SUBSTITUTE SPECIFICATION

DESCRIPTION

PLATING APPARATUS AND PLATING METHOD

Technical Field

The present invention relates to a plating apparatus and a plating method, and more particularly to a plating apparatus and a plating method used for filling a fine interconnect pattern formed in a substrate, such as a semiconductor substrate, with metal (interconnect material) such as copper so as to form interconnects.

Background Art

Recently, there has been employed a circuit forming method comprising forming fine recesses for interconnects, such as trenches or via holes in a circuit form, in a semiconductor substrate, embedding the fine recesses with copper (interconnect material) by copper plating, and removing a copper layer (plated film) at portions other than the fine recesses by CMP means or the like. In this method, from the viewpoint of reducing loads on subsequent CMP, it is desirable that a copper plated film be deposited selectively in trenches or via holes in a circuit form, and that the amount of copper plated film deposited on portions other than the trenches or via holes be small. In order to achieve such an object, there have heretofore been proposed various ideas regarding a plating solution, such as composition in a bath of a plating solution or a brightener used in a plating solution.

Meanwhile, in order to deposit a copper plated film selectively in trenches in a circuit form or the like, there has

been known a method of bringing a porous member into contact with a substrate such as a semiconductor wafer, and plating the substrate while relatively moving the porous member in a contact direction (for example, see Japanese laid-open patent publication No. 2000-232078). As a porous member in this method, there have generally been used PVA, porous Teflon (registered trademark), polypropylene knitted like a textile or skimmed like a paper, and unformed materials such as gelated silicon oxide or agar.

However, in order to embed interconnect material such as copper completely into pattern portions such as trenches so as to form copper interconnects, a considerably thick copper layer is formed on portions other than the pattern portions, and it is necessary to remove an excessive copper layer deposited on the portions other than the pattern portions by a CMP method. If the amount of copper to be removed is larger, then CMP requires a longer period of time, thereby causing an increased cost. Further, if a substrate has non-uniformity on its polished surface after CMP, then interconnects remaining after polishing have different depths over the surface of the substrate. Thus, a longer period of polishing time increases a degree of dependence of interconnect performance upon CMP performance.

In order to solve such drawbacks, there have been proposed various ideas regarding a plating solution, such as composition in a bath of the plating solution or a brightener used in a plating solution. These ideas can achieve the object to a certain extent but have a limitation.

On the other hand, in a method comprising bringing a porous member into contact with a substrate and plating the substrate

while relatively moving the porous member in a contact direction, a porous member, which generally has a surface roughness in a range of from several micrometers to several hundred micrometers, is problematic to planarize projections and depressions on a semiconductor substrate having a surface roughness in a range of from submicrometers to several micrometers.

Further, in this method, while the porous member is brought into contact with the substrate, the porous member is moved (rubbed) in the horizontal direction relative to the contact surface so that the amount of plating solution supplied is varied at projections and depressions. Thus, attempts to improve flatness are made. However, it is difficult to obtain expected results because of the surface roughness as described above. Further, it is difficult to uniformly press the overall surface of the porous member against the surface, to be plated, of the substrate so as to bring it into close contact with the surface of the substrate because of the surface roughness of the surface of the porous member, or undulations or warpages produced in the porous member when the porous member is pressed against the surface, to be plated, of the substrate. For this reason, as shown in FIG. 50, gaps S are locally formed between a porous member A and a surface P, to be plated, of a substrate W. A plating solution Q is present in the gaps S. Ions such as Cu^{2+} contained in the plating solution Q present in the gaps S contribute to plating. Thus, plating non-uniformity is caused over the surface of the substrate.

It is considered that flatness can be improved by increasing loads to bring the porous member into contact with the substrate

so as to eliminate the spaces in the porous member. In such a case, an extremely large load is applied to the substrate. Accordingly, in a case where a soft insulating film such as a low-k material is processed, the insulating film is broken, and a surface of a plated film is likely to be scratched. Thus, it has been difficult to put the above method into practice.

A plating apparatus having the following configuration has been known as this type of plating apparatus used for plating to form fine interconnects having high aspect ratios. A substrate is held in such a state that a surface (surface to be plated) of the substrate faces upward (in a face-up manner). A cathode electrode is brought into contact with a peripheral portion of the substrate so that the surface of the substrate serves as a cathode. An anode is disposed above the substrate. While a space between the substrate and the anode is filled with a plating solution, a plating voltage is applied between the substrate (cathode) and the anode to plate a surface (surface to be plated) of a substrate (for example, see Japanese laid-open patent publication No. 2002-506489).

In a plating apparatus in which a substrate is held and plated in single wafer processing while a surface of the substrate faces upward, a distribution of a plating current can be made more uniform over an entire surface of the substrate to improve uniformity of a plated film over the surface of the substrate. Generally, the substrate is transferred and subjected to various processes in such a state that a surface of the substrate faces upward. Accordingly, it is not necessary to turn the substrate at the time of plating.

However, in a conventional plating apparatus in which a substrate is held and plated in such a state that a surface of the substrate faces upward (in a face-up manner), a large amount of plating solution is required to be supplied in order to continuously supply a new plating solution between the substrate (cathode) and an anode to plate the substrate. Thus, the conventional plating apparatus has been problematic in wastefully consuming a plating solution.

From this point of view, a new plating solution to be used for plating is supplied to a substrate from a position near the substrate, in addition to a plating solution in which an anode is immersed and which is not to be used for actual plating. Thus, a small amount of a new plating solution is supplied from the position near the substrate, and the new plating solution thus supplied is used for actual plating. However, even though the new plating solution is supplied to the substrate from the position near the substrate, the used plating solution that has been deteriorated by immersion of the anode is actually circulated and mixed into the new plating solution. As a result, plating characteristics cannot be maintained or managed.

Disclosure of Invention

The present invention has been made in view of the above circumstances. It is therefore a first object of the present invention to provide a plating apparatus and a plating method which can selectively deposit a metal plated film such as a copper layer in fine recesses for interconnects, such as trenches or via holes in a circuit form.

It is a second object of the present invention to provide a plating apparatus and a plating method which can perform plating in such a state that an entire surface of a porous member is brought into close contact with a surface, to be plated, of the substrate uniformly, without increasing loads.

It is a third object of the present invention to provide a plating apparatus which can perform plating using a new plating solution at all times by supplying a smaller amount of the plating solution even in a face-up type plating apparatus.

According to the present invention, there is provided a plating apparatus comprising: an electrode head having an anode, a plating solution impregnated material for holding a plating solution, and a porous contact member which is brought into contact with a surface of a substrate; a cathode electrode which is brought into contact with the substrate to supply current to the substrate; a pressing mechanism for pressing the porous contact member of the electrode head against the surface of the substrate under a desired pressure; a power source for applying plating voltage between the anode and the cathode electrode; and a control unit for correlating and controlling the state of pressing the porous contact member of the electrode head against the surface of the substrate, and the state of plating voltage applied between the anode and the cathode electrode.

The present inventors have diligently studied a method for depositing a metal preferentially in trenches or via holes by supplying a plating solution to the trenches or the via holes in a substrate. As a result, the present inventors have found that a porous contact member having high flatness and such fine

through-holes that allow a plating solution to pass therethrough is brought into contact with the substrate on which a seed layer is formed, and application of voltage for plating is made intermittent in connection with a change of contact state between the porous contact member and the seed layer of the substrate, whereby metal deposition takes place preferentially in the trenches or the via holes.

The essence of the present invention is that plating is performed in such a state that the porous contact member of the electrode head is brought into contact with raised portions of the seed layer formed on the surface of the substrate. By performing plating in such a state that the porous contact member is brought into contact with the raised portions of the seed layer, components of additives (surface active agent or the like) having an effect of suppressing plating and contained in the plating solution adhere uniquely to the raised portions of the seed layer which are contacted by the porous contact member to suppress deposition of a plated film, and deposition of a plated film is performed in the recesses of the seed layer which are not contacted by the porous contact member.

In a case where the interface between the porous contact member and the seed layer of the substrate is stationary when the porous contact member contacts the seed layer of the substrate, this phenomenon takes place stably. Further, the more flatness the porous contact member has, the higher the stability is. Further, in a case where the porous contact member is composed of hydrophobic material, components of additives are more liable to adhere to the seed layer.

Further, a change of the state of plating voltage applied between the anode and the cathode electrode, and a change of pressing state between the porous contact member and the surface of the substrate are correlated, and plating performed for a short period of time and supply of a new plating solution are repeated. Consequently, the phenomenon of suppressing deposition of a plated film at the raised portions of the seed layer and performing deposition of a plated film in the recesses of the seed layer can be maintained, and hence an ideal plating action that the recesses of the seed layer are preferentially plated can be obtained.

The porous contact member is formed by polyethylene, polypropylene, polyamide, polycarbonate, polyimide, silicon carbide, or alumina, for example.

The plating solution impregnated material is formed by ceramics or porous plastics, for example.

At least a surface of the porous contact member which contacts the surface of the substrate is preferably formed by an insulator or a material having high insulation performance.

The control unit preferably controls so as to cause at least one of the porous contact member and the substrate to rotate on its own axis or rotate on an axis spaced from said own axis.

According to the present invention, there is provided another plating apparatus comprising: a substrate stage for holding a substrate; a cathode unit having a seal member for hermetically sealing a peripheral portion of a surface, to be plated, of the substrate by contacting the peripheral portion of the surface, to be plated, of the substrate held by the substrate

stage, and a cathode electrode which is brought into contact with the substrate to supply current to the substrate; an electrode head disposed above the cathode unit so as to be movable up and down and having an anode and a porous member with water retentivity at upper and lower parts of the electrode head; a plating solution supply unit for supplying a plating solution between the anode and the surface, to be plated, of the substrate held by the substrate stage; a pressing and separating mechanism for pressing the porous member against the surface, to be plated, of the substrate held by the substrate stage under a desired pressure and separating the porous member from the surface to be plated; and a power source for applying plating voltage between the cathode electrode and the anode.

According to the present invention, the porous member is pressed against the surface, to be plated, of the substrate held by the substrate stage under a desired pressure, the gaps between the porous member and portions other than fine recesses for interconnects, such as trenches in a surface, to be plated, of the substrate (portions other than a pattern) are made as small as possible, and in this state, plating is performed. Further, the porous member is separated from the substrate held by the substrate stage in the course of the process, the plating solution between the porous member and the substrate is refreshed (replaced), and then plating is performed again. Therefore, a plated film is selectively and efficiently deposited in the fine recesses for interconnects formed in the substrate. Further, by adjusting the pressure for pressing the porous member against the surface, to be plated, of the substrate to a desired value,

the surface, to be plated, of the substrate or the plated film which is being formed can be prevented from being damaged by the porous member.

A plating apparatus preferably comprises a relative movement mechanism for moving the substrate held by the substrate stage and the electrode head relative to each other.

For example, before plating, the porous member is pressed against the surface, to be plated, of the substrate held by the substrate stage under a desired pressure, and the porous member and the substrate are moved relatively to each other to heighten adhesiveness between the porous member and the substrate.

The relative movement mechanism comprises a rotating mechanism for rotating at least one of the substrate stage and the electrode head, for example.

A plating apparatus preferably comprises a torque sensor for detecting a rotating torque which is imparted when at least one of the substrate stage and the electrode head is rotated.

In this manner, the torque sensor is provided, and the pressure for pressing the porous member against the surface of the substrate to be plated is detected by the torque sensor. Therefore, this pressure is prevented from being excessively large, or from being insufficient.

The pressing and separating mechanism preferably has an air bag for pressing the porous member against the substrate by expansion and contraction with gas pressure.

With this arrangement, the porous member is uniformly pressed (pressurized) in its entire surface through the air bag, and hence the porous member can be brought into close contact

with the entire surface of the substrate under a more uniform pressure.

The air bag is preferably configured to contact the anode or the porous member and to move the anode or the porous member up and down in a horizontal state.

The porous member preferably has a multi-layered structure in which at least two kinds of porous materials are laminated.

From the viewpoint of material, structure, and the like, the porous member comprises a plating solution impregnated material serving to hold a plating solution mainly, and a porous pad attached to a lower surface of the plating solution impregnated material, for example. This porous pad comprises a lower pad to be brought into direct contact with the substrate, and an upper pad disposed between the lower pad and the plating solution impregnated material, for example. As described above, since the porous member has a multi-layered structure, it is possible to use the porous pad (the lower pad) which contacts the substrate, for example, and has a flatness enough to flatten irregularities on the surface to be plated of the semiconductor substrate.

The electrode head preferably has a housing which houses the anode and the air bag therein, and defines an anode chamber by closing a lower open end portion of the housing with the porous member. With this arrangement, the porous member can be pressed downwardly and independently through the air bag housed in the anode chamber.

The anode chamber has a cylindrical shape, for example. A gas introduction pipe communicating with the air bag, a plating solution introduction pipe for introducing the plating solution

into the anode chamber, and a power supply port for supplying power to the anode are attached to the housing.

The pressing and separating mechanism preferably has an air bag for moving the housing up and down.

With this arrangement, in a state such that the electrode head is fixed so as not to move up and down, only the housing which defines the anode chamber therein can be vertically moved relatively through the air bag.

According to a preferred aspect of the present invention, a plating apparatus further comprises a vibrating mechanism for vibrating the housing or the substrate stage up and down, from side to side, or in a circle.

With this arrangement, the housing or the substrate stage is vibrated in a vertical, right and left, or circular direction in such a state that the porous member is brought out of contact with the surface of the substrate to be plated. Thus, the plating solution can be run on the surface of the conductive layer such as a seed layer or the like formed on the surface (surface to be plated) of the substrate.

A plating apparatus preferably further comprises a temperature control mechanism for controlling a temperature of the plating solution in the anode chamber, and a temperature of the plating solution between the anode and the surface of the substrate to be plated held by the substrate stage.

With this arrangement, the temperature of the plating solution can be kept constant at all times during plating, and hence the film thickness and film quality of the metal film (plated film) can be prevented from being changed due to change of the

temperature of the plating solution.

The substrate stage is preferably configured to attract the backside surface of the peripheral portion of the substrate placed on the upper surface of the substrate stage and hold the substrate horizontally, and to pressurize the reverse side of the substrate by a fluid.

With this arrangement, the substrate held by the substrate stage is pressurized by the fluid from the reverse side of the substrate, and hence the substrate can be maintained in a horizontal state further to bring the substrate into close contact with the lower surface of the porous member.

According to a preferred aspect of the present invention, a plating apparatus further comprises a vibrating mechanism for vibrating the substrate held by the substrate stage or the porous member.

With this arrangement, for example, prior to plating, the porous member is pressed against the surface of the substrate held by the substrate stage under a desired pressure, and at least one of the substrate and the porous member is vibrated by an ultrasonic wave, a vibrator, or the like to heighten the adhesiveness between the porous member and the substrate.

The plating apparatus according to the present invention comprises a substrate stage for holding a substrate; a cathode unit having a seal member for hermetically sealing a peripheral portion of a surface of the substrate to be plated by contacting the peripheral portion of the surface of the substrate held by the substrate stage, and a cathode electrode which is brought into contact with the substrate to supply current to the substrate;

an electrode head disposed above the cathode unit so as to be movable up and down and having an anode and a porous member with water retentivity at upper and lower parts of the electrode head; a plating solution supply unit for supplying a plating solution between the anode and the surface of the substrate held by the substrate stage; a pressing mechanism for pressing the porous member against the surface of the substrate held by the substrate stage under a desired pressure; a power source for applying plating voltage between the cathode electrode and the anode; and a plating solution removing mechanism for removing the plating solution existing in a gap between the porous member and the surface of the substrate when the porous member is pressed against the surface of the substrate held by the substrate stage under a desired pressure.

According to the present invention, when the porous member is pressed against the surface of the substrate held by the substrate stage under a desired pressure, the plating solution existing in the gap between the porous member and the surface to be plated is removed, and hence plating can be performed in such a state that the entire surface of the porous member is uniformly brought into close contact with the surface of the substrate, without increasing loads.

The plating solution removing mechanism preferably comprises a mechanism for making relative motion of at least two of the substrate held by the substrate stage, the porous member, and the plating solution supplied between the anode and the surface of the substrate held by the substrate stage.

For example, before and after the porous member is pressed

against the substrate held by the substrate stage under a desired pressure, by rotating the substrate held by the substrate stage and the porous member relatively, the plating solution existing in the gap between the porous member and the surface of the substrate can be removed outwardly by a centrifugal force generated by this rotation.

The plating solution removing mechanism preferably comprises a mechanism for vibrating at least one of the substrate held by the substrate stage, the porous member, and the plating solution supplied between the anode and the surface of the substrate held by the substrate stage.

For example, by using the vibrator, the substrate held by the substrate stage or the porous member is vibrated. Therefore, the plating solution existing in the gap between the porous member and the surface of the substrate can be removed smoothly.

According to a preferred aspect of the present invention, the plating solution removing mechanism comprises a mechanism for vibrating at least one of the substrate held by the substrate stage, the porous member, and the plating solution supplied between the anode and the surface of the substrate held by the substrate stage vertically to the surface of the substrate held by the substrate stage.

With this arrangement, by vibrating the substrate vertically to the surface of the substrate, the porous member is not brought in sliding contact with the surface of the substrate. Thus, the plated surface can be prevented from being damaged.

The mechanism for vibrating comprises, for example, a mechanism which utilizes an ultrasonic wave or a mechanism which

uses a vibrator having an exciting coil. With this arrangement, by utilizing an ultrasonic wave, vibration at a high frequency can be imparted.

The mechanism for vibrating comprises a piezo transducer, for example. In this manner, by using the piezo transducer, the mechanism can be compact.

The mechanism for vibrating may utilize pressure vibration. By uliziizing pressure vibration, the plating solution can be mainly vibrated.

The plating solution removing mechanism preferably comprises an anode chamber which houses the anode therein and has an open end portion closed by the porous member, and a pressure control unit for controlling a pressure of the anode chamber.

With this arrangement, the anode chamber is evacuated to develop a pressure in the anode chamber lower than an atmospheric pressure (negative pressure), and the plating solution existing in the gap between the porous member and the surface, to be plated, of the substrate is drawn in to accelerate a flow of the plating solution into the anode chamber through the porous member, thereby removing the plating solution from the gap.

Still another plating apparatus according to the present invention comprises a substrate stage for holding a substrate; a cathode unit having a seal member for hermetically sealing a peripheral portion of a surface of the substrate to be plated by contacting the peripheral portion of the surface of the substrate held by the substrate stage, and a cathode electrode which is brought into contact with the substrate to supply current to the substrate; an electrode head disposed above the cathode

unit so as to be movable up and down and having an anode and a porous member with water retentivity at upper and lower parts of the electrode head; a plating solution supply unit for supplying a plating solution between the anode and the surface of the substrate held by the substrate stage; and a power source for applying plating voltage between the cathode electrode and the anode. The porous member has a multi-layered structure in which at least two kinds of porous materials are laminated.

According to the present invention, a new plating solution is held in advance in the interior of the porous member having a multi-layered structure, and the new plating solution is supplied to the substrate through the porous member immediately before plating. Therefore, the plating solution in which the anode is immersed is prevented from being mixed with a new plating solution to be supplied to the substrate, and plating can be performed using a new plating solution at all times by supplying a smaller amount of the plating solution.

The electrode head preferably has a housing which houses the anode therein, and defines an anode chamber by closing a lower open end portion of the housing with the porous member.

With this arrangement, the anode chamber becomes an air-tight space by closing the lower open end of the anode chamber with the porous member which holds the plating solution therein, and the plating solution is held in the anode chamber. Then, air-tight state of the anode chamber is released or the anode chamber is pressurized, whereby a new plating solution held in the porous member can be supplied to the substrate while the new plating solution is prevented from being mixed with the plating

solution which is held in the anode chamber and allows the anode to be immersed.

A plating solution suction pipe for sucking the plating solution into the anode chamber, a pressurized fluid introduction pipe for introducing a pressurized fluid into the anode chamber, and a power supply port for supplying power to the anode are preferably attached to the housing.

With this arrangement, in such a state that the porous member is immersed in a new plating solution, the plating solution in the anode chamber is sucked to thus suck and remove the used plating solution which allows the anode in the anode chamber to be immersed, and a new plating solution is introduced into the porous member and is held therein. Further, the anode chamber is pressurized by a pressurized fluid, and hence a new plating solution held in the porous member can be supplied to the substrate through the porous member.

At least one space is preferably formed between the porous materials which constitute the multi-layered structure.

With this arrangement, a new plating solution is held in advance in the space between the porous materials which constitute the multi-layered structure. The new plating solution held in this space and the plating solution held in the porous member located below the space can be supplied to the substrate and used for plating, while the plating solution in which the anode is immersed is prevented from being mixed with the new plating solution held in the space and the plating solution held in the porous material.

According to a preferred aspect of the present invention,

a plating apparatus further comprises a plating solution supply unit for discharging and supplying the plating solution to the space formed between the porous materials and a plating solution discharge unit for sucking and discharging the plating solution in the space.

Thus, while a new plating solution is supplied from the plating solution supply unit into the space between the porous materials, the plating solution is withdrawn from this space through the plating solution discharge unit, and hence the used plating solution in the space can be replaced with a new plating solution.

According to the plating method of the present invention, a plating method comprises preparing a substrate having fine recesses for interconnects covered with a seed layer; supplying a plating solution between a surface of the seed layer and an anode spaced from the seed layer at a certain interval through a porous contact·member; and plating the substrate by applying plating voltage between the seed layer and the anode; wherein a change of the state of plating voltage applied between the seed layer and the anode, and a change of pressing state between the porous contact member and the seed layer are correlated.

This plating method is characterized in that a plating solution is supplied between the seed layer on the substrate and the anode through the porous contact member, and plating is performed while correlating the state of plating voltage applied between the seed layer and the anode and the pressing state between the porous contact member and the seed layer, and changing the state of plating voltage applied between the seed layer and the

anode.

This porous contact member needs to have fine through-holes which allow the plating solution to pass therethrough. Further, in order to prevent a plated film from being deposited on the porous contact member, at least a contact surface between the porous contact member and the seed layer needs to be formed by an insulator or a material having high insulating properties.

Further, it is desirable that the porous contact member is composed of a material having a certain degree of hardness so that the porous contact member holds the flat surface (portions in which trenches and/or via holes in an interconnect form are formed) firmly, and so that a plated film is deposited on the flat surface of the substrate as little as possible. Further, the contact surface between the porous contact member and the seed layer preferably has high flatness so that contact area between the porous contact member and the surface of the seed layer can be large. It is desirable that a material of the porous contact member is hydrophobic in order to extract the effect of the additives (described later).

According to the plating method of the present invention, the change of the state of plating voltage applied between the seed layer and the anode includes intermittence of plating voltage applied between the porous contact member and the seed layer (application of rectangle voltage), an increase and decrease of plating voltage applied between the porous contact member and the seed layer (repetition of high-voltage and low-voltage), and the like. The method for applying plating voltage between the porous contact member and the seed layer may be the application

of simple direct current, or the application of a pulse group comprising a plurality of pulses, or the application of a sine wave.

Further, the change of pressing state between the porous contact member and the seed layer includes a change of contact and non-contact between the seed layer and the porous contact member and a change of pressure at the time of contact between the seed layer and the porous contact member from a relatively high pressure to a relatively low pressure.

The aspects of the method in which a change of the state of plating voltage applied between the seed layer and the anode, and a change of pressing state between the porous contact member and the seed layer are correlated to perform plating include the following aspects.

As a first aspect, the change of pressing state between the porous contact member and the seed layer includes a change of contact and non-contact between the porous contact member and the seed layer, a change of the state of plating voltage applied between the seed layer and the anode, and intermittence of plating voltage applied between the seed layer and the anode.

In this aspect, for example, when the porous contact member is brought into contact with the seed layer, a plating voltage is applied between the seed layer and the anode to perform plating, and when the porous contact member is brought out of contact with the seed layer, a plating voltage is not applied between the seed layer and the anode to stop plating, and a new plating solution is supplied between the seed layer and the porous contact member.

The contact and non-contact between the porous member and

the seed layer, and intermittence of application of plating voltage between the seed layer and the anode may be synchronized. Further, the timing for applying plating voltage between the seed layer and the anode may be slightly delayed from the contact between the porous member and the seed layer. In this aspect, the porous contact member or the substrate (seed layer) can be rotated or moved, for example, in such a state that a plating voltage is not applied between the seed layer and the anode. Particularly, in a case where the timing of application of plating voltage is retarded, although the porous contact member contacts the seed layer, it is desirable that the plating solution can be run on the surface of the seed layer by rotating the substrate or the porous contact member, or moving the substrate or the porous contact member up and down, or from side to side in such a state that the plating voltage is not applied between the seed layer and the anode. The running-in motion of the plating solution with respect to the surface of the seed layer includes motion of repeating contact and non-contact, motion of repeating high-pressure and low-pressure for pressing, motion of rotating the substrate in a state of slightly pressing, and the like.

As a second aspect, the change of pressing state between the porous contact member and the seed layer is a change of pressure between the porous contact member and the seed layer, and the change of the state of plating voltage applied between the seed layer and the anode is intermittence of plating voltage applied between the seed layer and the anode.

In this aspect, for example, a plating voltage is applied between the seed layer and the anode to perform plating when a

pressure between the porous contact member and the seed layer is relatively high, a plating voltage is not applied between the seed layer and the anode to stop plating when a pressure between the porous contact member and the seed layer is lowered and becomes relatively low, and a new plating solution is supplied between the seed layer and the porous contact member.

In this aspect also, while application of plating voltage is stopped, a plating solution can be run on the surface of the seed layer by rotating, moving, or vibrating the porous contact member or the substrate.

As a third aspect, the change of pressing state between the porous contact member and the seed layer is a change of pressure between the porous contact member and the seed layer, and the change of the state of plating voltage applied between the seed layer and the anode is a change of magnitude of plating voltage.

In this aspect, a relatively high plating voltage is applied to perform plating when a pressure between the porous contact member and the seed layer is relatively high, and a relatively low plating voltage is applied between the seed layer and the anode when a pressure between the porous contact member and the seed layer is lowered and becomes a low pressure. The plating solution which has been consumed when a high plating voltage is applied can be supplied when a low plating voltage is applied.

When a change of the state of plating voltage applied between the seed layer and the anode, and a change of pressing state between the porous contact member and the seed layer are correlated to perform plating, for example, the interval between application time of plating voltage and interruption time of plating voltage

may be constant or may be changed.

Further, one of voltage and current at the time of plating may be constant or both of voltage and current at the time of plating may be gradually changed. Further, at the initial stage of plating, plating may be performed at a constant voltage, and then at a constant current.

According to the plating method of the present invention, a thin metal plating may be performed on the seed layer of the substrate by a general method, before a change of the state of plating voltage applied between the seed layer and the anode, and a change of pressing state between the porous contact member and the seed layer are correlated and plating is performed. For example, plating is performed for a short period of time in such a state that the porous contact member is brought out of contact with the seed layer, and then the porous contact member is brought into contact with the seed layer, and the state of plating voltage applied between the seed layer and the anode and the pressing state between the porous contact member and the seed layer is correlated to perform plating.

The sort of plating solution used in the present invention is not particularly limited, and a plating solution which does not contain additives so much may be used. However, a plating solution which uses additives having high hydrophobicity is preferably used. Particularly, in a case where acid copper plating solution such as copper sulfate plating solution is used as a plating solution, additives which contain polymer component, carrier component and leveler component are preferably used. Particularly, a polymer component and a carrier component are

essential.

Another plating method of the present invention comprises preparing a substrate having fine recesses for interconnects covered with a seed layer; placing a porous member having water retentivity between the surface of the seed layer and an anode spaced from the seed layer at a certain interval; and plating the substrate by flowing current between the seed layer and the anode while filling a plating solution between the seed layer and the anode. While the porous member is pressed against the seed layer under a desired pressure, the plating is performed by flowing current between the seed layer and the anode.

According to a preferred aspect of the present invention, the porous member is pressed against the seed layer under a desired pressure, and the porous member and the seed layer are moved relatively to each other before performing the plating by flowing current between the seed layer and the anode.

According to a preferred aspect of the present invention, the flowing current between the seed layer and the anode is stopped, and the porous member is separated from the seed layer in the course of the process.

With this arrangement, the plating solution between the porous member and the seed layer can be refreshed (replaced) in the course of the process.

The plating method of the present invention comprises preparing a substrate having fine recesses for interconnects covered with a seed layer; placing a porous member having water retentivity between the surface of the seed layer and an anode spaced from the seed layer at a certain interval; plating the

substrate by flowing current between the seed layer and the anode while filling a plating solution between the seed layer and the anode; wherein the plating solution existing between the porous member and the seed layer is removed before and after the porous member is pressed against the seed layer under a desired pressure, and then current is flowed between the seed layer and the anode.

According to a preferred aspect of the present invention, the current is flowed only when the porous member is brought into contact with the seed layer.

A substrate processing apparatus of the present invention comprises a loading/unloading station for carrying in and out a substrate; a plating apparatus according to the present invention; a cleaning and drying apparatus for cleaning and drying the substrate; and a transfer apparatus for transferring the substrate between the loading/unloading station, the plating apparatus, and the cleaning and drying apparatus.

A substrate processing apparatus preferably comprises a polishing apparatus for polishing and removing unnecessary metal film formed on the surface of the substrate in the plating apparatus to planarize the surface of the substrate.

A substrate processing preferably comprises a heat treatment apparatus for performing heat treatment of the substrate on which a metal film is formed in the plating apparatus.

With this arrangement, before polishing and removing unnecessary metal film with a polishing apparatus, heat treatment (annealing) of the substrate may be conducted. This has a good effect on the polishing and removing treatment of unnecessary

metal film in the polishing apparatus, and electrical characteristic of the interconnects.

A substrate processing apparatus preferably further comprises a bevel etching apparatus for removing a metal film attached or deposited on the peripheral portion of the substrate by etching.

With this arrangement, for example, immediately after the metal film for embedding is deposited on the surface of the substrate, and the substrate is cleaned by the cleaning apparatus, the metal film deposited on the bevel of the substrate can be etched by the bevel etching apparatus.

A substrate processing apparatus preferably further comprises a monitor unit for monitoring at least one of a voltage value and a current value when the plating voltage is applied between the anode and the cathode electrode in the plating apparatus.

With this arrangement, an endpoint of plating in the plating apparatus can be detected by the monitor unit, and plating can be terminated by feedback.

A substrate processing apparatus preferably further comprises a film thickness measuring device for measuring a thickness of the metal film deposited on the surface of the substrate.

With this arrangement, the thickness of the metal film on the surface of the substrate is measured, and plating time is increased or decreased as needed by feedback of the measured results. Therefore, the metal film having a desired thickness can be formed with good reproducibility.

Brief Description of Drawings

FIGS. 1A-1D are views showing an example for forming interconnects in a semiconductor device in a sequence of steps;

FIG. 2 is a plan view of a substrate processing apparatus having a plating apparatus according to an embodiment of the present invention;

FIG. 3 is a schematic view showing an essential part of the plating apparatus shown in FIG. 2;

FIG. 4 is a time chart showing operation of the electrode head in the plating apparatus shown in FIG. 3;

FIG. 5 is a systematic diagram showing an example of a plating solution management system;

FIG. 6 is a front cross-sectional view showing an example of a cleaning and drying apparatus shown in FIG. 2;

FIG. 7 is a plan view showing an example of the cleaning and drying apparatus shown in FIG. 2;

FIG. 8 is a schematic view showing an example of a bevel etching and backside cleaning apparatus shown in FIG. 2;

FIG. 9 is a plan cross-sectional view showing an example of a heating treatment apparatus shown in FIG. 2;

FIG. 10 is a plan cross-sectional view showing an example of the heating treatment apparatus shown in FIG. 2;

FIG. 11 is a front view of a pretreatment apparatus shown in FIG. 2 at the time of substrate transfer;

FIG. 12 is a front view of the pretreatment apparatus shown in FIG. 2 at the time of chemical treatment;

FIG. 13 is a front view of the pretreatment apparatus shown

in FIG. 2 at the time of rinsing;

FIG. 14 is a cross-sectional view showing a processing head at the time of substrate transfer;

FIG. 15 is an enlarged view of portion A of FIG. 14 in the pretreatment apparatus shown in FIG. 2;

FIG. 16 is a view corresponding to FIG. 15 at the time of substrate fixing;

FIG. 17 is a systematic diagram of the pretreatment apparatus shown in FIG. 2;

FIG. 18 is a cross-sectional view showing a substrate head at the time of substrate transfer in an electroless plating apparatus shown in FIG. 2;

FIG. 19 is an enlarged view of portion B of FIG. 18;

FIG. 20 is a view corresponding to FIG. 19 showing the substrate head at the time of substrate fixing;

FIG. 21 is a view corresponding to FIG. 19 showing the substrate head at the time of a plating process;

FIG. 22 is a front view with partial cross-section showing a plating tank when a plating tank cover is closed;

FIG. 23 is a cross-sectional view of a cleaning tank in the pretreatment apparatus shown in FIG. 2;

FIG. 24 is a systematic diagram of the cleaning tank in the pretreatment apparatus shown in FIG. 2;

FIG. 25 is a schematic view showing an example of a polishing apparatus shown in FIG. 2;

FIG. 26 is a schematic front view of the area of a reversing machine in a film thickness measuring instrument shown in FIG. 2;

FIG. 27 is a plan view of a reversing arm section;

FIG. 28 is a flow chart in a substrate processing apparatus shown in FIG. 2;

FIG. 29 is a schematic view showing an essential part of a plating apparatus according to another embodiment of the present invention;

FIG. 30 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 31 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 32 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 33 is a schematic view showing an electrode head unit of a plating apparatus according to still another embodiment of the present invention;

FIG. 34 is a schematic view showing a plating apparatus having an electrode head shown in FIG. 33;

FIG. 35 is a schematic view showing a testing sample used in an example;

FIG. 36 is a graph showing application of voltage, contact and non-contact between a substrate and a porous contact member, and application of pressure;

FIG. 37 is a schematic view showing a copper layer obtained by an example;

FIG. 38 is a graph showing a condition of plating deposition

according to the present invention;

FIG. 39 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 40 is a view showing the state of removing a plating solution existing in gaps between the porous member and the surface of the substrate to be plated in the plating apparatus shown in FIG. 39;

FIG. 41 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 42 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 43 is a schematic view showing an essential part of a plating apparatus according to still another embodiment of the present invention;

FIG. 44 is a view showing the state of removing a plating solution existing in a gap between the porous member and the surface of the substrate to be plated in the plating apparatus shown in FIG. 43;

FIG. 45 is a plan view of a plating apparatus according to still another embodiment of the present invention;

FIG. 46 is a schematic cross-sectional view showing the state in which plating is performed in the plating apparatus shown in FIG. 45;

FIG. 47 is a cross-sectional view of a vertically movable housing showing a plating solution supply unit and a plating

solution discharge unit in the plating apparatus shown in FIG. 45;

FIG. 48 is a schematic cross-sectional view showing the state in which a new plating solution is supplied to an anode chamber of an electrode head in the plating apparatus shown in FIG. 45;

FIG. 49 is a schematic cross-sectional view showing another example of the state in which a new plating solution is supplied to an anode chamber of an electrode head in the plating apparatus shown in FIG. 45; and

FIG. 50 is a view showing the state in which a plating solution exists in gaps between the porous member and the surface of the substrate to be plated in a conventional example.

Best Mode for Carrying Out the Invention

A plating apparatus and a plating method according to embodiments of the present invention will be described below with reference to the drawings. The following embodiments show examples in which copper as an interconnect material is embedded in fine recesses for interconnects formed in a surface of a substrate such as a semiconductor wafer by plating so as to form interconnects composed of a copper layer. However, it should be noted that other kinds of interconnect materials may be used instead of copper.

FIGS. 1A through 1D illustrate an example of forming copper interconnects in a semiconductor device. As shown in FIG. 1A, an insulating film (i.e., an interlayer dielectric) 2, such as an oxide film of SiO_2 or a film of low-k material, is deposited

on a conductive layer 1a formed on a semiconductor base 1 having formed semiconductor devices. Via holes 3 and trenches 4 are formed in the insulating film 2 by performing a lithography/etching technique so as to provide fine recesses for interconnects. Thereafter, a barrier layer 5 of TaN or the like is formed on the insulating film 2, and a seed layer 6 as a feeding layer for electroplating is formed on the barrier layer 5 by sputtering or the like.

Then, as shown in FIG. 1B, copper plating is performed on a surface of a substrate W to fill the via holes 3 and the trenches 4 with copper and, at the same time, deposit a copper layer 7 on the insulating film 2. Thereafter, the barrier layer 5, the seed layer 6 and the copper layer 7 on the insulating film 2 are removed by chemical mechanical polishing (CMP) or the like so as to leave copper filled in the via holes 3 and the trenches 4, and have a surface of the insulating film 2 lie substantially on the same plane as this copper. Interconnects (copper interconnects) 8 composed of the seed layer 6 and the copper layer 7 are thus formed as shown in FIG. 1C.

Then, as shown in FIG. 1D, electroless plating is performed on a surface of the substrate W to selectively form a protective film 9 of a Co alloy, an Ni alloy, or the like on surfaces of the interconnects 8, thereby covering and protecting the exposed surfaces of the interconnects 8 with the protective film 9.

FIG. 2 is a plan view of a substrate processing apparatus incorporating a plating apparatus according to an embodiment of the present invention. As shown in FIG. 2, the substrate processing apparatus comprises a rectangular frame 12 to which

transfer boxes 10 such as SMIF (Standard Mechanical Interface) boxes which accommodate a number of substrates such as semiconductor wafers, are removably attached. Inside of the frame 12, there are disposed a loading/unloading station 14, and a movable transfer robot 16 for transferring a substrate to and from the loading/unloading station 14. A pair of plating apparatuses 18 is disposed on both sides of the transfer robot 16. A cleaning and drying apparatus 20, a bevel etching and backside cleaning apparatus 22, and a film thickness measuring instrument 24 are disposed in alignment with each other on one side of the transfer robot 16. On the other side of the transfer robot 16, a heat treatment (annealing) apparatus 26, a pretreatment apparatus 28, an electroless plating apparatus 30, and a polishing apparatus 32 are disposed in alignment with each other.

The frame 12 is shielded so as not to allow a light to transmit therethrough, thereby enabling subsequent processes to be performed under a light-shielded condition in the frame 12. Specifically, the subsequent processes can be performed without irradiating the interconnects with a light such as an illuminating light. By thus preventing the interconnects from being irradiated with a light, it is possible to prevent the interconnects of copper from being corroded due to a potential difference of light that is caused by application of light to the interconnects composed of copper, for example.

FIG. 3 schematically shows the plating apparatus according to the embodiment of the present invention. As shown in FIG. 3, the plating apparatus comprises a swing arm 500 which is

horizontally swingable. An electrode head 502 is rotatably supported by a tip end portion of the swing arm 500. A substrate stage 504 for holding a substrate W in such a state that a surface, to be plated, of the substrate W faces upwardly is vertically movably disposed below the electrode head 502. A cathode unit 506 is disposed above the substrate stage 504 so as to surround a peripheral portion of the substrate stage 504. In this embodiment, the electrode head 502, whose diameter is slightly smaller than that of the substrate stage 504, is used so that plating can be performed over the substantially entire surface of the substrate W without changing a relative position between the electrode head 502 and the substrate stage 504.

An annular vacuum attraction groove 504b communicating with a vacuum passage 504a provided in the substrate stage 504 is formed in a peripheral portion of an upper surface of the substrate stage 504. Seal rings 508 and 510 are provided on inward and outward sides of the vacuum attraction groove 504b, respectively. Further, a pressurizing recess 504c is formed in the upper surface of the substrate stage 504 and is positioned inwardly of the seal ring 508. This pressurizing recess 504c communicates with a pressurized fluid passage 504d extending in the substrate stage 504.

With the above structure, the substrate W is placed on the upper surface of the substrate stage 504, and the vacuum attraction groove 504b is evacuated through the vacuum passage 504a to attract the peripheral portion of the substrate W, thereby holding the substrate W. Then, a pressurized fluid such as pressurized air is supplied to the pressurizing recess 504c through the

pressurized fluid passage 504d to press the substrate W from the reverse side of the substrate under a pressure of P_5. Thus, the substrate W is kept in a horizontal state further, and hence the substrate W can be held in close contact with a lower surface of a porous member 528, which will be described later.

Although not shown in the drawings, the substrate stage 504 incorporates a heating device (e.g., heater) for keeping a temperature of the substrate stage 504 constant. Further, the substrate stage 504 is moved up and down by an air cylinder (not shown), and is rotated together with the cathode unit 506 at desired acceleration and speed by a rotating motor and a belt (not shown). A rotational torque is measured by a torque sensor (not shown) when the substrate stage 504 is being rotated. When the substrate stage 504 is moved upwardly, the peripheral portion of the substrate W held by the substrate stage 504 is brought into contact with a seal member 514 and cathode electrodes 512 (described later) of the cathode unit 506.

An elevating/lowering motor (not shown) comprising a servomotor and a ball screw (not shown) are used to move the swing arm 500 up and down, and a swinging motor (not shown) is used to rotate (swing) the swing arm 500. Alternatively, a pneumatic actuator may be used.

In this embodiment, the cathode unit 506 has cathode electrodes 512 comprising six cathode electrodes, and the annular seal member 514 disposed above the cathode electrodes 512 so as to cover upper surfaces of the cathode electrodes 512. The seal member 514 has an inner circumferential portion which is inclined inwardly and downwardly so that a thickness of the seal member

514 is gradually reduced. The seal member 514 has an inner circumferential edge portion extending downwardly.

With this structure, when the substrate stage 504 is moved upwardly, the peripheral portion of the substrate W held by the substrate stage 504 is pressed against the cathode electrodes 512, thus flowing current to the substrate W. At the same time, the inner circumferential edge portion of the seal member 514 is held in close contact with the upper surface of the peripheral portion of the substrate W to seal a contact portion hermetically. Accordingly, a plating solution that has been supplied onto the upper surface (surface to be plated) of the substrate W is prevented from leaking from the end portion of the substrate W, and the cathode electrodes 512 are thus prevented from being contaminated by the plating solution.

In this embodiment, the cathode unit 506 is not movable up and down, but is rotatable together with the substrate stage 504. However, the cathode unit 506 may be designed to be movable up and down so that the seal member 514 is brought into close contact with the surface of the substrate W when the cathode unit 506 is moved downwardly.

The above-mentioned electrode head 502 comprises a rotatable housing 520 and a vertically movable housing 522, which have a bottomed cylindrical shape with a downwardly open end and are disposed concentrically. The rotatable housing 520 is fixed to a lower surface of a rotating member 524 attached to a free end of the swing arm 500 so that the rotatable housing 520 is rotated together with the rotating member 524. An upper portion of the vertically movable housing 522 is positioned inside the

rotatable housing 520, and the vertically movable housing 522 is rotated together with the rotatable housing 520 and is moved relative to the rotatable housing 520 up and down. The vertically movable housing 522 defines an anode chamber 530 by closing the lower open end of the vertically movable housing 522 with a porous member 528 so that a circular anode 526 is disposed in the anode chamber 530 and is dipped in a plating solution Q which is introduced to the anode chamber 530.

In this embodiment, the porous member 528 has a multi-layered structure comprising three-layers of laminated porous materials. Specifically, the porous member 528 comprises a plating solution impregnated material 532 serving to hold a plating solution mainly, and a porous pad 534 attached to a lower surface of the plating solution impregnated material 532. This porous pad 534 comprises a lower pad 534a adapted to be brought into direct contact with the substrate W, and an upper pad 534b disposed between the lower pad 534a and the plating solution impregnated material 532. The plating solution impregnated material 532 and the upper pad 534b are positioned in the vertically movable housing 522, and the lower open end of the vertically movable housing 522 is closed by the lower pad 534a.

As described above, since the porous member 528 has a multi-layered structure, it is possible to use the porous pad 534 (the lower pad 534a) which contacts the substrate, for example, and has flatness enough to flatten irregularities on the surface, to be plated, of the substrate W.

The lower pad 534a is required to have the contact surface adapted to contact the surface (surface to be contacted) of the

substrate W and having a certain degree of flatness, and to have fine through-holes therein for allowing the plating solution to pass therethrough. It is also necessary that at least the contact surface of the lower pad 534a is made of an insulator or a material having high insulating properties. The surface of the lower pad 534a is required to have a maximum roughness (RMS) of about several tens μm or less.

It is desirable that the fine through-holes of the lower pad 534a have a circular cross section in order to maintain flatness of the contact surface. An optimum diameter of each of the fine through-holes and the optimum number of the fine through-holes per unit area vary depending on the kind of plated film and interconnect pattern. However, it is desirable that both the diameter and the number are as small as possible in view of improving selectivity of a plated film which is growing in a recess. Specifically, the diameter of each of the fine through-holes may be not more than 30 μm, preferably in the range of 5 to 20 μm. The number of the fine through-holes having such diameter per unit area may be represented by a porosity of not more than 50%.

Further, it is desirable that the lower pad 534a has a certain degree of hardness. For example, the lower pad 534a may have a tensile strength ranging from 5 to 100 kg/cm^2 and a bend elastic constant ranging from 200 to 10000 kg/cm^2.

Furthermore, it is desirable that the lower pad 534a is made of hydrophilic material. For example, the following materials may be used after being subjected to hydrophilization or being introduced with a hydrophilic group by polymerization.

Examples of such materials include porous polyethylene (PE), porous polypropylene (PP), porous polyamide, porous polycarbonate, and porous polyimide. The porous polyethylene (PE), the porous polypropylene (PP), the porous polyamide, and the like are produced by using fine powder of ultrahigh-molecular polyethylene, polypropylene, and polyamide, or the like as a material, squeezing the fine powder, and sintering and forming the squeezed fine powder. These materials are commercially available. For example, "Furudasu S (trade name)" manufactured by Mitsubishi Plastics, Inc, "Sunfine UF (trade name)", "Sunfine AQ (trade name)", both of which are manufactured by Asahi Kasei Corporation, and "Spacy (trade name)" manufactured by Spacy Chemical Corporation are available on the market. The porous polycarbonate may be produced by passing a high-energy heavy metal such as copper, which has been accelerated by an accelerator, through a polycarbonate film to form straight tracks, and then selectively etching the tracks.

The lower pad 534a may be produced by a flattening process in which the surface, to be brought into contact with the surface of the substrate W, of the lower pad 534a is compacted or machined to a flat finish for thereby enabling a highly preferential deposition in the fine recesses.

On the other hand, the plating solution impregnated material 532 is composed of porous ceramics such as alumina, SiC, mullite, zirconia, titania or cordierite, or a hard porous member such as a sintered compact of polypropylene or polyethylene, or a composite material comprising these materials. In case of the alumina-based ceramics, for example, the ceramics with a pore

diameter of 30 to 200μm is used. In case of the SiC, SiC with a pore diameter of not more than 30μm, a porosity of 20 to 95%, and a thickness of about 1 to 20mm, preferably 5 to 20mm, more preferably 8 to 15mm, is used. The plating solution impregnated material 532, in this embodiment, is composed of porous ceramics of alumina having a porosity of 30%, and an average pore diameter of 100μm. The porous ceramic plate per se is an insulator, but is constructed so as to have a smaller conductivity than the plating solution by causing the plating solution to enter its interior in a complicated manner and follow a considerably long path in the thickness direction.

In this manner, the plating solution impregnated material 532 is disposed in the anode chamber 530, and generates high resistance. Hence, the influence of the resistance of the seed layer 6 (see FIG. 1A) becomes a negligible amount. Consequently, the difference in current density over the surface of the substrate due to electrical resistance on the surface of the substrate W becomes small, and the uniformity of the plated film over the surface of the substrate improves.

The electrode head 502 has a pressing and separating mechanism having three air bags (in this embodiment) for pressing the lower pad 534a against the surface (surface to be plated) of the substrate W held by the substrate stage 504 under a desired pressure and separating the lower pad 534a from the surface of the substrate W. Specifically, in this embodiment, a ring-shaped first air bag 540 is provided between the lower surface of the top wall of the rotatable housing 520 and the upper surface of the top wall of the vertically movable housing 522, and a

ring-shaped second air bag 542 is provided in the vertically movable housing 522 and between the lower surface of the top wall of the vertically movable housing 522 and the upper surface of the anode 526. Further, a bottomed cylindrical member 544 which projects upwardly and extends through the rotatable housing 520 is provided continuously on the central portion of the vertically movable housing 522, and a circular air bag 546 is provided between the lower surface of the top wall of the bottomed cylindrical member 544 and the upper surface of the top wall of the rotatable housing 520. These air bags 540, 542 and 546 are connected to a pressurized fluid source (not shown) through respective pressurized fluid introduction pipes 550, 552 and 554. These air bags 540, 542 and 546 jointly serve as the pressing and separating mechanism.

Specifically, as shown in FIG. 3, the swing arm 500 is fixed at a predetermined position (process location) so as not to move up and down, and then the interior of the air bag 540 is pressurized under a pressure of P_1, the interior of the air bag 542 is pressurized under a pressure of P_2, and the interior of the air bag 546 is pressurized under a pressure of P_4, whereby the lower pad 534a is pressed against the surface (surface to be plated) of the substrate W held by the substrate stage 504 under a desired pressure. Thereafter, the pressures P_1, P_2 and P_4 are restored to an atmospheric pressure to separate the lower pad 534a from the surface of the substrate W. Thus, the vertically movable housing 522 is more uniformly pressed over the entire surface in a horizontal direction of the vertically movable housing 522 through the first air bag 540 and the third air bag 546, and the anode

526 in the anode chamber 530 is more uniformly pressed over the entire surface of the anode 526 through the second air bag 542, whereby the entire surface of the lower pad 534a is brought into close contact with the entire surface of the substrate W held by the substrate stage 504.

A plating solution introduction pipe 556 is attached to the vertically movable housing 522 to introduce the plating solution into the vertically movable housing 522, and a pressurized fluid introduction pipe 558 is attached to the vertically movable housing 522 to introduce a pressurized fluid into the vertically movable housing 522. A number of pores 526a are formed within the anode 526. Thus, a plating solution Q is introduced from the plating solution introduction pipe 556 into the anode chamber 530, and the interior of the anode chamber 530 is pressurized under a pressure of P_3, whereby the plating solution Q reaches the upper surface of the plating solution impregnated material 532 through the pores 526a of the anode 526, and reaches the upper surface of the substrate W held by the substrate stage 504 through the interior of the plating solution impregnated material 532 and interior of the porous pad 534 (the upper pad 534b and the lower pad 534a).

The anode chamber 530 includes gases generated by chemical reaction therein, and hence the pressure in the anode chamber 530 may be varied. Therefore, the pressure P_3 in the anode chamber 530 is controlled to a certain set value by a feedback control in the process.

For example, in the case of performing copper plating, in order to suppress slime formation, the anode 526 is made of copper

(phosphorus-containing copper) containing 0.03 to 0.05% of phosphorus. The anode 526 may comprise an insoluble metal such as platinum or titanium or an insoluble electrode comprising metal on which platinum or the like is plated. Since replacement or the like is unnecessary, the insoluble metal or the insoluble electrode is preferable. Further, the anode 526 may be a net-like anode which allows a plating solution to pass therethrough easily.

The cathode electrodes 512 are electrically connected to a cathode of a plating power source 560, and the anode 526 is electrically connected to an anode of the plating power source 560. The vertically movable housing 522 is provided with a feeding port 562 connected to the plating power source 560 for supplying power to the anode 526.

Next, an operation for conducting plating with the plating apparatus 18 will be described with reference to FIG. 4.

First, in a state that the substrate W is attracted to and held by the upper surface of the substrate stage 504, the substrate stage 504 is raised to bring the peripheral portion of the substrate W into contact with the cathode electrodes 512, thus making it possible to supply current to the substrate W. Then, the substrate stage 504 is further raised to press the seal member 514 against the upper surface of the peripheral portion of the substrate W, thereby hermetically sealing the peripheral portion of the substrate W by the seal member 514.

On the other hand, the electrode head 502 is moved from a position (idling position) where replacement of the plating solution, removal of bubbles, and the like are conducted by idling to a predetermined position (process position) in such a state

that the plating solution Q is held inside the electrode head 502. Specifically, the swing arm 500 is once raised and further swung, whereby the electrode head 502 is located immediately above the substrate stage 504. Thereafter, the electrode head 502 is lowered, and when the electrode head 502 reaches the predetermined position (process position), the electrode head 502 is stopped. Then, the anode chamber 530 is pressurized to a pressure of P_3, and the plating solution Q held by the electrode head 502 is discharged from the lower surface of the porous pad 534.

Next, pressurized air is introduced into the air bags 540, 542 and 546, and at the same time, pressurized air is introduced into the pressurizing recess 504c of the substrate stage 504, whereby the vertically movable housing 522 is lowered, and further the lower pad 534a is pressed downwardly. At the same time, the substrate W held by the substrate stage 504 is pressed from its reverse side, and hence the lower pad 534a is pressed against the surface (surface to be plated) of the substrate under a given pressure. Thus, the substrate W is maintained in a horizontal state further and the lower pad 534a is pressed against the entire surface of the substrate W under a more uniform pressure.

In this state, the electrode head 502 and the substrate stage 504 are rotated (rotated on their own axes). In this manner, before plating, the lower pad 534a is pressed against the surface of the substrate W held by the substrate stage 504 under a desired pressure, and the lower pad 534a and the substrate W are moved relatively to each other to heighten adhesiveness between the lower pad 534a and the substrate W. After rotation of the electrode head 502 and the substrate stage 504 is stopped, the cathode

electrodes 512 are connected to the cathode of the plating power source 560 and the anode 526 is connected to the anode of the plating power source 560, thereby plating the surface of the substrate W. In this manner, the lower pad 534a is pressed against the surface of the substrate W held by the substrate stage 504 under a desired pressure, and adhesiveness between the lower pad 534a and the substrate W is heightened, thereby plating the surface of the substrate W. Therefore, the gaps between the lower pad 534a and portions other than fine recesses for interconnects such as trenches in a surface of the substrate W (portions other than pattern portion) are made as small as possible, and hence a plated film is selectively deposited in the fine recesses for interconnects formed in the surface of the substrate.

After plating is performed for a certain period of time, the cathode electrodes 512 and the anode 526 are disconnected from the plating power source 560, the anode chamber 530 is restored to atmospheric pressure, and the air bags 540, 542 and 546 are restored to atmospheric pressure, thereby separating the lower pad 534a from the substrate W. In this manner, the plating solution between the lower pad 534a and the substrate W is refreshed (replaced).

Next, in the same manner as the above, a pressurized fluid is introduced into the air bags 540, 542 and 546 to press the lower pad 534a against the substrate W under a desired pressure, and a pressurized fluid is introduced also into the anode chamber 530. In this state, the electrode head 502 and the substrate stage 504 are rotated, and after rotation of the electrode head 502 and the substrate stage 504 is stopped, the cathode electrodes

512 and the anode 526 are connected to the plating power source 560, thereby performing plating of the surface of the substrate W. In this manner, the lower pad 534a is separated from the substrate W held by the substrate stage 504 in the course of the process, the plating solution between the lower pad 534a and the substrate W is refreshed (replaced), and then plating is performed again. Therefore, a plated film can be selectively and efficiently deposited in the fine recesses for interconnects formed in the surface of the substrate. Further, by adjusting the pressure for pressing the lower pad 534a against the surface of the substrate W to a desired value, the surface of the substrate W or the plated film which is being formed can be prevented from being damaged by the lower pad 534a.

The above operation is repeated plural times, as needed (in FIG. 4, the state in which the operation is repeated twice is shown), then the air bags 540, 542 and 546, the pressurizing recess 504c of the substrate stage 504, and further the anode chamber 530 are restored to atmospheric pressure, and the swing arm 500 is raised and further swung to return the electrode head 502 to its original position (idling position).

FIG. 5 shows a plating solution management and supply system for supplying a plating solution whose composition, temperature, and the like are controlled to the plating apparatus. As shown in FIG. 5, a plating solution tray 600 for allowing the electrode head 502 of the plating apparatus 18 to be immersed for idling is provided, and the plating solution tray 600 is connected to a reservoir 604 through a plating solution discharge pipe 602.

The plating solution discharged through the plating solution discharge pipe 602 flows into the reservoir 604.

The plating solution which has flowed into the reservoir 604 is introduced into the plating solution regulating tank 608 by operating a pump 606. This plating solution regulating tank 608 is provided with a temperature controller 610, and a plating solution analyzing unit 612 for sampling the plating solution and analyzing the sample solution. Further, component replenishing pipes 614 for replenishing the plating solution with components which are found to be insufficient by an analysis performed by the plating solution analyzing unit 612 are connected to the plating solution regulating tank 608. When a pump 616 is operated, the plating solution in the plating solution regulating tank 608 flows in the plating solution supply pipe 618, passes through the filter 620, and is then returned to the plating solution tray 600.

In this manner, the composition and temperature of the plating solution is adjusted to be constant in the plating solution regulating tank 608, and the adjusted plating solution is supplied to the electrode head 502 of the plating apparatus 18. Then, by holding the adjusted plating solution by the electrode head 502, the plating solution having constant composition and temperature at all times can be supplied to the electrode head 502 of the plating apparatus 18.

FIGS. 6 and 7 show an example of a cleaning and drying apparatus 20 for cleaning (rinsing) the substrate W and drying the substrate W. Specifically, the cleaning and drying apparatus 20 performs chemical cleaning and pure water cleaning (rinsing)

first, and then completely drying the substrate W which has been cleaned by spindle rotation. The cleaning and drying apparatus 20 comprises a substrate stage 422 having a clamp mechanism 420 for clamping an edge portion of the substrate W, and a substrate mounting and removing lifting/lowering plate 424 for opening and closing the clamp mechanism 420. The substrate stage 422 is coupled to an upper end of a spindle 426 which is rotated at a high speed by energization of a spindle rotating motor (not shown). Further, a cleaning cup 428 for preventing a treatment liquid from being scattered around is disposed around the substrate W held by the clamp mechanism 420, and the cleaning cup 428 is vertically moved by actuation of a cylinder (not shown).

Further, the cleaning and drying apparatus 20 comprises a chemical liquid nozzle 430 for supplying a treatment liquid to the surface of the substrate W held by the clamp mechanism 420, a plurality of pure water nozzles 432 for supplying pure water to the backside surface of the substrate W, and a pencil-type cleaning sponge 434 which is disposed above the substrate W held by the clamp mechanism 420 and is rotatable. The pencil-type cleaning sponge 434 is attached to a free end of a swing arm 436 which is swingable in a horizontal direction. Clean air introduction ports 438 for introducing clean air into the apparatus are provided at the upper part of the cleaning and drying apparatus 20.

With the cleaning and drying apparatus 20 having the above structure, the substrate W is held by the clamp mechanism 420 and is rotated by the clamp mechanism 420, and while the swing arm 436 is swung, a treatment liquid is supplied from the chemical

liquid nozzle 430 to the cleaning sponge 434, and the surface of the substrate W is rubbed with the pencil-type cleaning sponge 434, thereby cleaning the surface of the substrate W. Further, pure water is supplied to the backside surface of the substrate W from the pure water nozzles 432, and the backside surface of the substrate W is simultaneously cleaned (rinsed) by the pure water ejected from the pure water nozzles 432. Thus cleaned substrate W is spin-dried by rotating the spindle 426 at a high speed.

FIG. 8 shows an example of a bevel etching and backside cleaning apparatus 22. The bevel etching and backside cleaning apparatus 22 can perform etching of the copper layer 7 (see FIG. 1B) deposited on an edge (bevel) of the substrate and backside cleaning simultaneously, and can suppress growth of a natural oxide film of copper at the circuit formation portion on the surface of the substrate. The bevel etching and backside cleaning apparatus 22 has a substrate stage 922 positioned inside a bottomed cylindrical waterproof cover 920 and adapted to rotate the substrate W at a high speed, in such a state that the face of the substrate W faces upward, while holding the substrate W horizontally by spin chucks 921 at a plurality of locations along a circumferential direction of a peripheral edge portion of the substrate, a center nozzle 924 placed above a nearly central portion of the face of the substrate W held by the substrate stage 922, and an edge nozzle 926 placed above the peripheral edge portion of the substrate W. The center nozzle 924 and the edge nozzle 926 are directed downward. A back nozzle 928 is positioned below a nearly central portion of the backside of the substrate W, and

directed upward. The edge nozzle 926 is adapted to be movable in a diametrical direction and a height direction of the substrate W.

The width of movement L of the edge nozzle 926 is set such that the edge nozzle 926 can be arbitrarily positioned in a direction toward the center from the outer peripheral end surface of the substrate, and a value for L is set to a desired value, according to the size, usage, or the like of the substrate W. Normally, an edge cut width C is set in the range of 2 mm to 5 mm. In the case where a rotational speed of the substrate is a certain value or higher at which the amount of liquid migration from the backside to the face is not problematic, the copper layer and the like within the edge cut width C can be removed.

Next, the method of cleaning with this bevel etching and backside cleaning apparatus 22 will be described. First, the substrate W is horizontally rotated integrally with the substrate stage 922, with the substrate being held horizontally by the spin chucks 921 of the substrate stage 922. In this state, an acid solution is supplied from the center nozzle 924 to the central portion of the face of the substrate W. The acid solution may be a non-oxidizing acid, and hydrofluoric acid, hydrochloric acid, sulfuric acid, citric acid, oxalic acid, or the like is used. On the other hand, an oxidizing agent solution is supplied continuously or intermittently from the edge nozzle 926 to the peripheral edge portion of the substrate W. As the oxidizing agent solution, one of an aqueous solution of ozone, an aqueous solution of hydrogen peroxide, an aqueous solution of nitric acid, and an aqueous solution of sodium hypochlorite is used, or a

combination of these is used.

In this manner, the copper layer or the like formed on the upper surface and end surface in the region of the edge cut width C of the substrate W is rapidly oxidized with the oxidizing agent solution, and is simultaneously etched with the acid solution supplied from the center nozzle 924 and spread on the entire face of the substrate, whereby it is dissolved and removed. By mixing the acid solution and the oxidizing agent solution at the peripheral edge portion of the substrate, a steep etching profile can be obtained, in comparison with a mixture of them which is produced in advance being supplied. At this time, the copper etching rate is determined by their concentrations. If a natural oxide film of copper is formed in the circuit-formed portion on the face of the substrate, this natural oxide is immediately removed by the acid solution spreading on the entire face of the substrate according to rotation of the substrate, and does not grow any more. After the supply of the acid solution from the center nozzle 924 is stopped, the supply of the oxidizing agent solution from the edge nozzle 926 is stopped. As a result, silicon exposed on the surface is oxidized, and deposition of copper can be suppressed.

On the other hand, an oxidizing agent solution and a silicon oxide film etching agent are supplied simultaneously or alternately from the back nozzle 928 to the central portion of the backside of the substrate. Therefore, copper or the like adhering in a metal form to the backside of the substrate W can be oxidized with the oxidizing agent solution, together with silicon of the substrate, and can be etched and removed with the

silicon oxide film etching agent. This oxidizing agent solution is preferably the same as the oxidizing agent solution supplied to the face, because the types of chemicals are decreased in number. Hydrofluoric acid can be used as the silicon oxide film etching agent, and if hydrofluoric acid is used as the acid solution on the face of the substrate, the types of chemicals can be decreased in number. Thus, if the supply of the oxidizing agent is stopped first, a hydrophobic surface is obtained. If the etching agent solution is stopped first, a water-saturated surface (a hydrophilic surface) is obtained, and thus the backside surface can be adjusted to a condition that will satisfy the requirements of a subsequent process.

In this manner, the acid solution, i.e., etching solution, is supplied to the substrate W to remove metal ions remaining on the surface of the substrate W. Then, pure water is supplied to replace the etching solution with pure water and remove the etching solution, and then the substrate is dried by spin-drying. In this way, removal of the copper layer in the edge cut width C at the peripheral edge portion on the face of the substrate, and removal of copper contaminants on the backside, are performed simultaneously to thus allow this treatment to be completed, for example, within 80 seconds. The etching cut width of the edge can be set arbitrarily (from 2 to 5 mm), but the time required for etching does not depend on the cut width.

FIGS. 9 and 10 show a heat treatment (annealing) apparatus 26. The annealing apparatus 26 comprises a chamber 1002 having a gate 1000 for taking in and taking out the substrate W, a hot plate 1004 disposed at an upper position in the chamber 1002 for

heating the substrate W to e.g. 400°C, and a cool plate 1006 disposed at a lower position in the chamber 1002 for cooling the substrate W by, for example, flowing cooling water inside the plate. The annealing apparatus 26 also has a plurality of vertically movable elevating pins 1008 penetrating the cool plate 1006 and extending upward and downward therethrough for placing and holding the semiconductor substrate W on them. The annealing apparatus further includes a gas introduction pipe 1010 for introducing an antioxidant gas between the substrate W and the hot plate 1004 during annealing, and a gas discharge pipe 1012 for discharging the gas which has been introduced from the gas introduction pipe 1010 and flowed between the substrate W and the hot plate 1004. The pipes 1010 and 1012 are disposed on the opposite sides of the hot plate 1004.

The gas introduction pipe 1010 is connected to a mixed gas introduction line 1022 which in turn is connected to a mixer 1020 where a N_2 gas introduced through a N_2 gas introduction line 1016 containing a filter 1014a, and a H_2 gas introduced through a H_2 gas introduction line 1018 containing a filter 1014b, are mixed to form a mixed gas which flows through the line 1022 into the gas introduction pipe 1010.

In operation, the substrate W, which has been carried in the chamber 1002 through the gate 1000, is held on the elevating pins 1008 and the elevating pins 1008 are raised up to a position at which the distance between the substrate W held on the lifting pins 1008 and the hot plate 1004 becomes about 0.1 to 1.0 mm, for example. In this state, the substrate W is then heated to e.g. 400°C through the hot plate 1004 and, at the same time, the

antioxidant gas is introduced from the gas introduction pipe 1010 and the gas is allowed to flow between the substrate W and the hot plate 1004 while the gas is discharged from the gas discharge pipe 1012, thereby annealing the substrate W while preventing its oxidation. The annealing treatment may be completed in about several tens of seconds to 60 seconds. The heating temperature of the substrate may be selected in the range of 100 to 600°C.

After the completion of the annealing, the elevating pins 1008 are lowered down to a position at which the distance between the substrate W held on the elevating pins 1008 and the cool plate 1006 becomes 0 to 0.5 mm, for example. In this state, by introducing cooling water into the cool plate 1006, the substrate W is cooled by the cool plate to a temperature of 100°C or lower in about 10 to 60 seconds. The cooled substrate is transferred to the next step.

A mixed gas of N_2 gas with several percentages of H_2 gas is used as the above antioxidant gas. However, N_2 gas may be used singly.

FIGS. 11 through 17 show a pretreatment apparatus 28 for performing a pretreatment of electroless plating of the substrate. The pretreatment apparatus 28 includes a fixed frame 52 that is mounted on the upper part of a frame 50, and a movable frame 54 that moves up and down relative to the fixed frame 52. A processing head 60, which includes a bottomed cylindrical housing portion 56, opening downwardly, and a substrate holder 58, is suspended from and supported by the movable frame 54. In particular, a servomotor 62 for rotating the head is mounted to the movable frame 54, and the housing portion 56 of the processing head 60

is coupled to the lower end of the downward-extending output shaft (hollow shaft) 64 of the servomotor 62.

As shown in FIG. 14, a vertical shaft 68, which rotates together with the output shaft 64 via a spline 66, is inserted in the output shaft 64, and the substrate holder 58 of the processing head 60 is coupled to the lower end of the vertical shaft 68 via a ball joint 70. The substrate holder 58 is positioned within the housing portion 56. The upper end of the vertical shaft 68 is coupled via a bearing 72 and a bracket to a fixed ring-elevating cylinder 74 secured to the movable frame 54. Thus, by the actuation of the cylinder 74, the vertical shaft 68 moves up and down independently of the output shaft 64.

Linear guides 76, which extend up and down and guide vertical movement of the movable frame 54, are mounted to the fixed frame 52, so that by the actuation of a head-elevating cylinder (not shown), the movable frame 54 moves up and down by the guide of the linear guides 76.

Substrate insertion windows 56a for inserting the substrate W into the housing portion 56 are formed in the circumferential wall of the housing portion 56 of the processing head 60. Further, as shown in FIGS. 15 and 16, a seal ring 84 is provided in the lower portion of the housing portion 56 of the processing head 60, an outer peripheral portion of the seal ring 84 being sandwiched between a main frame 80 made of e.g. PEEK and a guide frame 82 made of e.g. polyethylene. The seal ring 84 is provided to make contact with a peripheral portion of the lower surface of the substrate W to seal the peripheral portion.

On the other hand, a substrate fixing ring 86 is fixed to

a peripheral portion of the lower surface of the substrate holder 58. A columnar pusher 90 protrudes downwardly from the lower surface of the substrate fixing ring 86 by the elastic force of a spring 88 disposed within the substrate fixing ring 86 of the substrate holder 58. Further, a flexible cylindrical bellows-like plate 92 made of e.g. Teflon (registered trademark) is disposed between the upper surface of the substrate holder 58 and the upper wall of the housing portion 56 to hermetically seal the interior of the housing portion.

When the substrate holder 58 is in a raised position, a substrate W is inserted from the substrate insertion window 56a into the housing portion 56. The substrate W is then guided by a tapered surface 82a provided in the inner circumferential surface of the guide frame 82, and positioned and placed at a predetermined position on the upper surface of the seal ring 84. In this state, the substrate holder 58 is lowered so as to bring the pusher 90 of the substrate fixing ring 86 into contact with the upper surface of the substrate W. The substrate holder 58 is further lowered so as to press the substrate W downwardly by the elastic force of the spring 88, thereby forcing the seal ring 84 to make pressure contact with a peripheral portion of the front surface (lower surface) of the substrate W to seal the peripheral portion while nipping the substrate W between the housing portion 56 and the substrate holder 58 to hold the substrate W.

When the head-rotating servomotor 62 is driven while the substrate W is thus held by the substrate holder 58, the output shaft 64 and the vertical shaft 68 inserted in the output shaft 64 rotate together via the spline 66, whereby the substrate holder

58 rotates together with the housing portion 56.

At a position below the processing head 60, there is provided an upward-open treatment tank 100 comprising an outer tank 100a and an inner tank 100b which have a slightly larger inner diameter than the outer diameter of the processing head 60. A pair of leg portions 104, which is mounted to a lid 102, is rotatably supported on the outer circumferential portion of the treatment tank 100. Further, a crank 106 is integrally coupled to each leg portion 106, and the free end of the crank 106 is rotatably coupled to the rod 110 of a lid-moving cylinder 108. Thus, by the actuation of the lid-moving cylinder 108, the lid 102 moves between a treatment position at which the lid 102 covers the top opening of the treatment tank 100 and a retreat position beside the treatment tank 100. In the surface (upper surface) of the lid 102, there is provided a nozzle plate 112 having a large number of jet nozzles 112 for jetting outwardly (upwardly), electrolytic ionic water having reducing power, for example.

Further, as shown in FIG. 17, a nozzle plate 124 having a plurality of jet nozzles 124a for jetting upwardly a chemical liquid supplied from a chemical liquid tank 120 by driving the chemical liquid pump 122 is provided in the inner tank 100b of the treatment tank 100 in such a manner that the jet nozzles 124a are equally distributed over the entire surface of the cross section of the inner tank 100b. A drain pipe 126 for draining a chemical liquid (waste liquid) to the outside is connected to the bottom of the inner tank 100b. A three-way valve 128 is provided in the drain pipe 126, and the chemical liquid (waste liquid) is returned to the chemical liquid tank 120 through a

return pipe 130 connected to one of ports of the three-way valve 128 to recycle the chemical liquid, as needed. Further, in this embodiment, the nozzle plate 112 provided on the surface (upper surface) of the lid 102 is connected to a rinsing liquid supply source 132 for supplying a rinsing liquid such as pure water. Further, a drain pipe 127 is connected to the bottom of the outer tank 100a.

By lowering the processing head 60 holding the substrate so as to cover or close the top opening of the treatment tank 100 with the processing head 60 and then jetting a chemical liquid from the jet nozzles 124a of the nozzle plate 124 disposed in the treatment tank 100 toward the substrate W, the chemical liquid can be jetted uniformly onto the entire lower surface (processing surface) of the substrate W and the chemical liquid can be discharged out from the discharge pipe 126 while preventing scattering of the chemical liquid to the outside. Further, by raising the processing head 60 and closing the top opening of the treatment tank 100 with the lid 102, and then jetting a rinsing liquid from the jet nozzles 112a of the nozzle plate 112 disposed in the upper surface of the lid 102 toward the substrate W held in the processing head 60, the rinsing treatment (cleaning treatment) is carried out to remove the chemical liquid from the surface of the substrate. Because the rinsing liquid passes through the clearance between the outer tank 100a and the inner tank 100b and is discharged through the drain pipe 127, the rinsing liquid is prevented from flowing into the inner tank 100b and from being mixed with the chemical liquid.

According to the pretreatment apparatus 28, the substrate

W is inserted into the processing head 60 and held therein when the processing head 60 is in the raised position, as shown in FIG. 11. Thereafter, as shown in FIG. 12, the processing head 60 is lowered to the position at which it covers the top opening of the treatment tank 100. While rotating the processing head 60 and thereby rotating the substrate W held in the processing head 60, a chemical liquid is jetted from the jet nozzles 124a of the nozzle plate 124 disposed in the treatment tank 100 toward the substrate W, thereby jetting the chemical liquid uniformly onto the entire surface of the substrate W. The processing head 60 is raised and stopped at a predetermined position and, as shown in FIG. 13, the lid 102 in the retreat position is moved to the position at which it covers the top opening of the treatment tank 100. A rinsing liquid is then jetted from the jet nozzles 112a of the nozzle plate 112 disposed in the upper surface of the lid 102 toward the rotating substrate W held in the processing head 60. The chemical treatment by the chemical liquid and the rinsing treatment by the rinsing liquid of the substrate W can thus be carried out successively while avoiding mixing of the two liquids.

The lowermost position of the processing head 60 may be adjusted to adjust the distance between the substrate W held in the processing head 60 and the nozzle plate 124, whereby the region of the substrate W onto which the chemical liquid is jetted from the jet nozzles 124a of the nozzle plate 124 and the jetting pressure can be adjusted as desired. Here, when the pretreatment liquid such as a chemical liquid is circulated and reused, active components are reduced by progress of the treatment, and the pretreatment liquid (chemical liquid) is taken out due to

attachment of the treatment liquid to the substrate. Therefore, it is desirable to provide a pretreatment liquid management unit (not shown) for analyzing composition of the pretreatment liquid and adding insufficient components. Specifically, a chemical liquid used for cleaning is mainly composed of acid or alkali. Therefore, for example, a pH of the chemical liquid is measured, a decreased content is replenished from the difference between a preset value and the measured pH, and a decreased amount is replenished using a liquid level meter provided in the chemical storage tank. Further, with respect to a catalytic liquid, for example, in the case of acid palladium solution, the amount of acid is measured by its pH, and the amount of palladium is measured by a titration method or nephelometry, and a decreased amount can be replenished in the same manner as the above.

FIGS. 18 through 24 show an electroless plating apparatus 30. This electroless plating apparatus 30 which is provided to form the protective layer 9 shown in FIG. 1D includes a plating tank 200 (see FIGS. 22 and 24) and a substrate head 204, disposed above the plating tank 200, for detachably holding a substrate W.

As shown in detail in FIG. 18, the processing head 204 has a housing 230 and a head assembly 232. The head assembly 232 mainly comprises a suction head 234 and a substrate receiver 236 for surrounding the suction head 234. The housing 230 accommodates therein a substrate rotating motor 238 and substrate receiver drive cylinders 240. The substrate rotating motor 238 has an output shaft (hollow shaft) 242 having an upper end coupled to a rotary joint 244 and a lower end coupled to the suction head

234 of the head assembly 232. The substrate receiver drive cylinders 240 have respective rods coupled to the substrate receiver 236 of the head assembly 232. Stoppers 246 are provided in the housing 230 for mechanically limiting upward movement of the substrate receiver 236.

The suction head 234 and the substrate receiver 236 are operatively connected to each other by a splined structure such that when the substrate receiver drive cylinders 240 are actuated, the substrate receiver 236 vertically moves relative to the suction head 234, and when the substrate rotating motor 238 is energized, the output shaft 242 thereof is rotated to rotate the suction head 234 and the substrate receiver 236 in unison with each other.

As shown in detail in FIGS. 19 through 21, a suction ring 250 for attracting and holding a substrate W against its lower surface to be sealed is mounted on a lower circumferential edge of the suction head 234 by a presser ring 251. The suction ring 250 has a recess 250a continuously defined in a lower surface thereof in a circumferential direction and in communication with a vacuum line 252 extending through the suction head 234 by a communication hole 250b that is defined in the suction ring 250. When the recess 250a is evacuated, the substrate W is attracted to and held by the suction ring 250. Because the substrate W is attracted under vacuum to the suction ring 250 along a radially narrow circumferential area provided by the recess 250a, any adverse effects such as flexing caused by the vacuum on the substrate W are minimized. When the suction ring 250 is dipped in the plating solution (treatment liquid), not only the surface

(lower surface) of the substrate W, but also its circumferential edge, can be dipped in the plating solution. The substrate W is released from the suction ring 250 by introducing N_2 into the vacuum line 252.

The substrate receiver 236 is in the form of a downwardly open, hollow bottomed cylinder having substrate insertion windows 236a defined in a circumferential wall thereof for inserting therethrough the substrate W into the substrate receiver 236. The substrate receiver 236 also has an annular ledge 254 projecting inwardly from its lower end, and an annular protrusion 256 disposed on an upper surface of the annular ledge 254 and having a tapered inner circumferential surface 256a for guiding the substrate W.

As shown in FIG. 19, when the substrate receiver 236 is lowered, the substrate W is inserted through the substrate insertion window 236a into the substrate receiver 236. The substrate W thus inserted is guided by the tapered surface 256a of the protrusion 256 and positioned thereby onto the upper surface of the ledge 254 in a predetermined position thereon. The substrate receiver 236 is then elevated until it brings the upper surface of the substrate W placed on the ledge 254 into abutment against the suction ring 250 of the suction head 234, as shown in FIG. 20. Then, the recess 250a in the vacuum ring 250 is evacuated through the vacuum line 252 to attract the substrate W while sealing the upper peripheral edge surface of the substrate W against the lower surface of the suction ring 250. In order to plate the substrate W, as shown in FIG. 21, the substrate receiver 236 is lowered several mm to space the substrate W from the ledge 254, keeping the substrate W attracted only by the suction ring

250. The substrate W now has its lower peripheral edge surface prevented from not being plated because it is held out of contact with the ledge 254.

FIG. 22 shows the details of the plating tank 200. The plating tank 200 is connected at the bottom to a plating solution supply pipe 308 (see FIG. 24), and is provided in the peripheral wall with a plating solution recovery groove 260. In the plating tank 200, there are disposed two current plates 262 and 264 for stabilizing the flow of a plating solution flowing upward. A thermometer 266 for measuring the temperature of the plating solution introduced into the plating tank 200 is disposed at the bottom of the plating tank 200. Further, on the outer surface of the peripheral wall of the plating tank 200 and at a position slightly higher than the liquid level of the plating solution held in the plating tank 200, there is provided a jet nozzle 268 for jetting a stop liquid which is a neutral liquid having a pH of 6 to 7.5, for example, pure water, inwardly and slightly upwardly in the normal direction. After plating, the substrate W held in the head portion 232 is raised and stopped at a position slightly above the surface of the plating solution. In this state, pure water (stop liquid) is immediately jetted from the jet nozzle 268 toward the substrate W to cool the substrate W, thereby preventing progress of plating by the plating solution remaining on the substrate W.

Further, at the top opening of the plating tank 200, there is provided a plating tank cover 270 which closes the top opening of the plating tank 200 in a non-plating time, such as idling time, so as to prevent unnecessary evaporation of the plating

solution from the plating tank 200.

As shown in FIG. 24, a plating solution supply pipe 308 extending from a plating solution storage tank 302 and having a plating solution supply pump 304 and a three-way valve 306 is connected to the plating tank 200 at the bottom of the plating tank 200. With this arrangement, during a plating process, a plating solution is supplied into the plating tank 200 from the bottom of the plating tank 200, and the overflowing plating solution is recovered by the plating solution storage tank 302 through the plating solution recovery groove 260. Thus, the plating solution can be circulated. A plating solution return pipe 312 for returning the plating solution to the plating solution storage tank 302 is connected to one of the ports of the three-way valve 306. Thus, the plating solution can be circulated even in a standby condition of plating, and a plating solution circulating system is constructed. As described above, the plating solution in the plating solution storage tank 302 is always circulated through the plating solution circulating system, and hence a lowering rate of the concentration of the plating solution can be reduced and the number of the substrates W which can be processed can be increased, compared with the case in which the plating solution is simply stored.

Particularly, in this embodiment, by controlling the plating solution supply pump 304, the flow rate of the plating solution which is circulated at a standby of plating or at a plating process can be set individually. Specifically, the amount of circulating plating solution at the standby of plating is in the range of 2 to 20 liters/minute, for example, and the amount of

circulating plating solution at the plating process is in the range of 0 to 10 liters/minute, for example. With this arrangement, a large amount of circulating plating solution at the standby of plating can be ensured to keep a temperature of the plating bath in the cell constant, and the flow rate of the circulating plating solution is made smaller at the plating process to form a protective film (plated film) having a more uniform thickness.

The thermometer 266 provided in the vicinity of the bottom of the plating tank 200 measures a temperature of the plating solution introduced into the plating tank 200, and controls a heater 316 and a flow meter 318 described below.

Specifically, in this embodiment, there are provided a heating device 322 for heating the plating solution indirectly by a heat exchanger 320 which is provided in the plating solution in the plating solution storage tank 302 and uses water as a heating medium which has been heated by a separate heater 316 and has passed through the flow meter 318, and a stirring pump 324 for mixing the plating solution by circulating the plating solution in the plating solution storage tank 302. This is because in the electroless plating, in some cases, the plating solution is used at a high temperature (about 80 ℃), and the structure should cope with such cases. This method can prevent very delicate plating solution from being mixed with foreign matter or the like, unlike an in-line heating method.

FIG. 23 shows the details of a cleaning tank 202 provided beside the plating tank 200. At the bottom of the cleaning tank 202, there is provided a nozzle plate 282 having a plurality of jet nozzles 280, attached thereto, for upwardly jetting a rinsing

liquid such as pure water. The nozzle plate 282 is coupled to an upper end of a nozzle lifting shaft 284. The nozzle lifting shaft 284 can be moved up and down by changing the position of engagement between a nozzle position adjustment screw 287 and a nut 288 engaging the screw 287 so as to optimize the distance between the jet nozzles 280 and a substrate W located above the jet nozzles 280.

Further, on the outer surface of the peripheral wall of the cleaning tank 202 and at a position above the jet nozzles 280, there is provided a head cleaning nozzle 286 for jetting a cleaning liquid, such as pure water, inwardly and slightly downwardly onto at least a portion, which was in contact with the plating solution, of the head portion 232 of the substrate head 204.

In operating the cleaning tank 202, the substrate W held in the head portion 232 of the substrate head 204 is located at a predetermined position in the cleaning tank 202. A cleaning liquid (rinsing liquid), such as pure water, is jetted from the jet nozzles 280 to clean (rinse) the substrate W, and at the same time, a cleaning liquid such as pure water is jetted from the head cleaning nozzle 286 to clean at least a portion, which was in contact with the plating solution, of the head portion 232 of the substrate head 204, thereby preventing a deposit from accumulating on that portion which was immersed in the plating solution.

According to this electroless plating apparatus 30, when the substrate head 204 is in a raised position, the substrate W is held by vacuum attraction in the head portion 232 of the

substrate head 204 as described above, while the plating solution in the plating tank 200 is allowed to circulate.

When plating is performed, the plating tank cover 270 is opened, and the substrate head 204 is lowered, while the substrate head 204 is rotating, so that the substrate W held in the head portion 232 is immersed in the plating solution in the plating tank 200.

After immersing the substrate W in the plating solution for a predetermined time, the substrate head 204 is raised to lift the substrate W from the plating solution in the plating tank 200 and, as needed, pure water (stop liquid) is immediately jetted from the jet nozzle 268 toward the substrate W to cool the substrate W, as described above. The substrate head 204 is further raised to lift the substrate W to a position above the plating tank 200, and the rotation of the substrate head 204 is stopped.

Next, while the substrate W is held by vacuum attraction in the head portion 232 of the substrate head 204, the substrate head 204 is moved to a position right above the cleaning tank 202. While rotating the substrate head 204, the substrate head 204 is lowered to a predetermined position in the cleaning tank 202. A cleaning liquid (rinsing liquid), such as pure water, is jetted from the jet nozzles 280 to clean (rinse) the substrate W, and at the same time, a cleaning liquid such as pure water is jetted from the head cleaning nozzle 286 to clean at least a portion, which was in contact with the plating solution, of the head portion 232 of the substrate head 204.

After completion of cleaning of the substrate W, the rotation

of the substrate head 204 is stopped, and the substrate head 204 is raised to lift the substrate W to a position above the cleaning tank 202. Further, the substrate head 204 is moved to the transfer position between the transfer robot 16 and the substrate head 204, and the substrate W is transferred to the transfer robot 16, and is transported to a next process by the transfer robot 16.

As shown in FIG. 24, the electroless plating apparatus 30 is provided with a plating solution management unit 330 for analyzing composition of the plating solution by an absorptiometric method, a titration method, an electrochemical measurement, or the like, and replenishing components which are insufficient in the plating solution. In the plating solution management unit 330, signals indicative of the analysis results are processed to replenish insufficient components from a replenishment tank (not shown) to the plating solution storage tank 302 using a metering pump, thereby controlling the amount of the plating solution and composition of the plating solution. Thus, thin film plating can be realized with good reproducibility.

The plating solution management unit 330 has a dissolved oxygen densitometer 332 for measuring dissolved oxygen in the plating solution held by the electroless plating apparatus 30 by an electrochemical method, for example. According to the plating solution management unit 330, dissolved oxygen concentration in the plating solution can be controlled at a constant value on the basis of indication of the dissolved oxygen densitometer 332 by deaeration, nitrogen blowing, or other methods. In this manner, the dissolved oxygen concentration in the plating

solution can be controlled at a constant value, and the plating reaction can be achieved with reproducibility.

When the plating solution is used repeatedly, certain components are accumulated by being carried in from the outside or decomposition of the plating solution, resulting in lowering of reproducibility of plating and deteriorating of film quality. By adding a mechanism for removing such specific components selectively, the life of the plating solution can be prolonged and the reproducibility can be improved.

FIG. 25 shows an example of a polishing apparatus (CMP apparatus) 32. The polishing apparatus 32 comprises a polishing table 822 having a polishing surface composed of a polishing cloth (polishing pad) 820 which is attached to the upper surface of the polishing table 822, and a top ring 824 for holding a substrate W with its to-be-polished surface facing the polishing table 822. In the polishing apparatus 32, the surface of the substrate W is polished by rotating the polishing table 822 and the top ring 824 about their own axes, respectively, and supplying a polishing liquid from a polishing liquid nozzle 826 provided above the polishing table 822 while pressing the substrate W against the polishing cloth 820 of the polishing table 822 at a given pressure by means of the top ring 824. It is possible to use a fixed abrasive type of pad containing fixed abrasive particles as the polishing pad.

The polishing power of the polishing surface of the polishing cloth 820 decreases with a continuation of a polishing operation of the CMP apparatus. In order to restore the polishing power, a dresser 828 is provided to conduct dressing of the polishing

cloth 820, for example, at the time of replacing the substrate W. In the dressing, while rotating the dresser 328 and the polishing table 822 respectively, the dressing surface (dressing member) of the dresser 828 is pressed against the polishing cloth 820 of the polishing table 822, thereby removing the polishing liquid and chips adhering to the polishing surface and, at the same time, flattening and dressing the polishing surface, whereby the polishing surface is regenerated. The polishing table 822 may be provided with a monitor for monitoring the surface state of the substrate to detect in situ the end point of polishing, or with a monitor for inspecting in situ the finish state of the substrate.

FIGS. 26 and 27 show the film thickness measuring instrument 24 provided with a reversing machine. As shown in the FIGS. 26 and 27, the film thickness measuring instrument 24 is provided with a reversing machine 339. The reversing machine 339 includes reversing arms 353, 353. The reversing arms 353, 353 put a substrate W therebetween and hold its outer periphery from right and left sides, and rotate the substrate W through 180°, thereby turning the substrate over. A circular mounting base 355 is disposed immediately below the reversing arms 353, 353 (reversing stage), and a plurality of film thickness sensors S are provided on the mounting base 355. The mounting base 355 is adapted to be movable upward and downward by a drive mechanism 357.

During reversing of the substrate W, the mounting base 355 waits at a position, indicated by solid lines, below the substrate W. Before or after reversing, the mounting base 355 is raised to a position indicated by dotted lines to bring the film thickness

sensors S close to the substrate W gripped by the reversing arms 353, 353, thereby measuring the film thickness.

According to this embodiment, since there is no restriction such as the arms of the transfer robot, the film thickness sensors S can be installed at arbitrary positions on the mounting base 355. Further, the mounting base 355 is adapted to be movable upward and downward, so that the distance between the substrate W and the sensors S can be adjusted at the time of measurement. It is also possible to mount plural types of sensors suitable for the purpose of detection, and change the distance between the substrate W and the sensors each time measurements are made by the respective sensors. However, the mounting base 355 moves upward and downward, thus requiring certain measuring time.

An eddy current sensor, for example, may be used as the film thickness sensor S. The eddy current sensor measures a film thickness by generating an eddy current and detecting the frequency or loss of the current that has returned through the substrate W, and is used in a non-contact manner. An optical sensor may also be suitable for the film thickness sensor S. The optical sensor irradiates a light onto a sample, and measures a film thickness directly based on information of the reflected light. The optical sensor can measure a film thickness not only for a metal film but also for an insulating film such as an oxide film. Places for setting the film thickness sensor S are not limited to those shown in the drawings, but the sensor may be set at any desired places for measurement in any desired numbers.

Next, a sequence of processing for forming copper interconnects on the substrate W having the seed layer 6 formed

thereon which is carried out by the substrate processing apparatus having the above structure will be described with reference to FIG. 28.

First, the substrate W having the seed layer 6 formed in its surface is taken out one by one from a transfer box 10, and is carried in the loading/unloading station 14. The substrate W which has carried in the loading/unloading station 14 is transferred to the thickness measuring instrument 24 by the transfer robot 16, and an initial film thickness (film thickness of the seed layer 6) is measured by the thickness measuring instrument 24. Thereafter, if necessary, the substrate is inverted and transferred to the plating apparatus 18. In the plating apparatus 18, as shown in FIG. 1B, the copper layer 7 is deposited on the surface of the substrate W to embed copper. Then, the substrate W having the copper layer 7 formed thereon is transferred to the cleaning and drying apparatus 20 by the transfer robot 16, and the substrate W is cleaned by pure water and spin-dried. Alternatively, in a case where a spin-drying function is provided in the plating apparatus 18, the substrate W is spin-dried (removal of liquid) in the plating apparatus 18, and then the dried substrate is transferred to the bevel etching and backside cleaning apparatus 22.

In the bevel etching and backside cleaning apparatus 22, unnecessary copper attached to the bevel (edge) of the substrate W is removed by etching, and at the same time, the backside surface of the substrate is cleaned by pure water or the like. Thereafter, as described above, the substrate W is transferred to the cleaning and drying apparatus 20 by the transfer robot 16, and the substrate

W is cleaned by pure water and spin-dried. Alternatively, in a case where a spin-drying function is provided in the bevel etching and backside cleaning apparatus 22, the substrate W is spin-dried in the bevel etching and backside cleaning apparatus 22, and then the dried substrate is transferred to the heat treatment apparatus 26 by the transfer robot 16.

In the heat treatment apparatus 26, heat treatment (annealing) of the substrate W is carried out. Then, the substrate W after the heat treatment is transferred to the film thickness measuring instrument 24 by the transfer robot 16, and the film thickness of copper is measured by the film thickness measuring instrument 24. The film thickness of the copper layer 7 (see FIG. 1B) is obtained from the difference between this measured result and the measured result of the above initial film thickness. Then, for example, plating time of a subsequent substrate is adjusted according to the measured film thickness. If the film thickness of the copper layer 7 is insufficient, then additional formation of copper layer is performed by plating again. Then, the substrate W after the film thickness measurement is transferred to the polishing apparatus 32 by the transfer robot 16.

As shown in FIG. 1C, unnecessary copper layer 7 and the seed layer 6 deposited on the surface of the substrate W are polished and removed by the polishing apparatus 32 to planarize the surface of the substrate W. At this time, for example, the film thickness and the finishing state of the substrate are inspected by a monitor, and when an endpoint is detected by the monitor, polishing is finished. Then, the substrate W which has been polished is

transferred to the cleaning and drying apparatus 20 by the transfer robot 16, and the surface of the substrate is cleaned by a chemical liquid and then cleaned (rinsed) with pure water, and then spin-dried by rotating the substrate at a high speed in the cleaning and drying apparatus 20. After this spin-drying, the substrate W is transferred to the pretreatment apparatus 28 by the transfer robot 16.

In the pretreatment apparatus 28, a pretreatment before plating comprising at least one of attachment of Pd catalyst to the surface of the substrate and removal of oxide film attached to the exposed surface of the substrate, for example, is carried out. Then, the substrate after this pretreatment, as described above, is transferred to the cleaning and drying apparatus 20 by the transfer robot 16, and the substrate W is cleaned by pure water and spin-dried. Alternatively, in a case where a spin-drying function is provided in the pretreatment apparatus 28, the substrate W is spin-dried (removal of liquid) in the pretreatment apparatus 28, and then the dried substrate is transferred to the electroless plating apparatus 30 by the transfer robot 16.

In the electroless plating apparatus 30, as shown in FIG. 1D, for example, electroless CoWP plating is applied to the surface of the exposed interconnects 8 to form a protective film (plated film) 9 composed of CoWP alloy selectively on the exposed surface of the interconnects 8, thereby protecting the interconnects 8. The thickness of the protective film 9 is in the range of 0.1 to 500 nm, preferably in the range of 1 to 200 nm, more preferably in the range of 10 to 100 nm. At this time, for example, the

thickness of the protective film 9 is monitored, and when the film thickness reaches a predetermined value, i.e., an endpoint is detected, the electroless plating is finished.

After the electroless plating, the substrate W is transferred to the cleaning and drying apparatus 20 by the transfer robot 16, and the surface of the substrate is cleaned by a chemical liquid, and cleaned (rinsed) with pure water, and then spin-dried by rotating the substrate at a high speed in the cleaning and drying apparatus 20. After the spin-drying, the substrate W is returned into the transfer box 10 via the loading/unloading station 14 by the transfer robot 16.

FIG. 29 shows a plating apparatus according to another embodiment of the present invention. The plating apparatus according to the embodiment shown in FIG. 29 is different from the plating apparatus shown in FIG. 3 in that the substrate stage 504 has a substrate placing surface 504e which is formed into a flat surface, and the substrate W is directly brought into contact with the substrate placing surface 504e and is placed on and held by the substrate placing surface 504e. Other structure is the same as that of the apparatus shown in FIG. 3.

FIG. 30 shows a plating apparatus according to still another embodiment of the present invention. The plating apparatus according to this embodiment shown in FIG. 30 is different from the plating apparatus shown in FIG. 3 in that the substrate stage 504 has a recess 504f at the surface thereof, a backing film 564 is attached in the recess 504f, and the substrate W is brought into contact with the surface of the backing film 564 and is placed on and held by the backing film 564. Other structure is the same

as that of the apparatus shown in FIG. 3.

FIG. 31 shows a plating apparatus according to still another embodiment of the present invention. The plating apparatus according to the embodiment shown in FIG. 31 is different from the plating apparatus shown in FIG. 30 in that the electrode head 502 having a smaller diameter than the substrate stage 504 is used. In this embodiment, since the diameter of the electrode head 502 is smaller than that of the substrate stage 504, if plating is carried out in such a state that the electrode head 502 and the substrate stage 504 are fixed to each other, plating cannot be performed over the entire surface of the substrate W held by the substrate stage 504. Thus, in this embodiment, when the cathode electrodes 512 and the anode 526 are connected to the plating power source 560 and plating is performed, the electrode head 502 is swung by the swing arm 500, and at the same time, at least one of the electrode head 502 and the substrate stage 504 is rotated. Other structure is the same as that of the apparatus shown in FIG. 30.

FIG. 32 shows a plating apparatus according to still another embodiment of the present invention. The plating apparatus according to this embodiment shown in FIG. 32 is different from the plating apparatus shown in FIG. 29 in that a driving member 580 which is rotatable, and is vertically movable independently of the swing arm 500 to serve as a pressing and separating mechanism is attached to the free end of the swing arm 500, and in that the driving member 580 and the vertically movable housing 522 which houses the anode 526 therein and defines the anode chamber 530 by closing the lower open end of the vertically movable housing

522 with a porous member 528 are coupled to each other by a ball bearing 584 through a supporting member 582 disposed in the vertically movable housing 522, whereby when the driving member 580 is moved upward and downward, the ball bearing 584 presses the vertically movable housing 522 in such a manner that a load converges on a point.

In this embodiment, a flange 580a is provided on the driving member 580, and a flange 582a serving as a stopper is provided on the supporting member 582. Stopper pins 588 which project downwardly are attached to the flange 580a of the driving member 580 in such a state that elastic forces are applied to the stopper pins 588 by compression coil springs 586, and the lower ends of the stopper pins 588 contact the flange (stopper) 582a of the supporting member 582 elastically, thereby keeping the supporting member 582 and the vertically movable housing 522 horizontal. Other structure is the same as that of the apparatus shown in FIG. 29.

In the above embodiments, copper is used as an interconnect material. However, besides copper, a copper alloy, silver, a silver alloy, and the like may be used. This holds true for the following embodiments.

According to the present invention, plating is performed preferentially into trenches or via holes to embed an interconnect material (metal film) therein, and hence flatness of the surface after plating can be improved. Thus, a load of a selective etching process applied to raised portions such as CMP can be reduced or eliminated, and hence, in addition to a reduction in costs, problems unique to CMP such as dishing or oxide erosion can be

solved.

FIGS. 33 and 34 show essential parts of the plating apparatus according to still another embodiment of the present invention. The plating apparatus has an electrode head 701 in which a porous contact member 702, a plating solution impregnated material 703, and an anode 704 are housed in an anode chamber 706 within a housing 707, and the electrode head 701 is attached to the main shaft 710 through a supporting member 711 and an air bag 709. A seal ring 708 and cathode electrodes 712 are attached to the lower end of the housing 707. In this drawing, a substrate W having a seed layer 6 formed on a surface of the substrate W is shown.

The electrode head 701 comprises the anode 704, the plating solution impregnated material 703, and the porous contact member 702 which are arranged in the housing 707 in this order. The porous contact member 702 provided at the lowermost position of the electrode head 701 has the substantially the same structure as the lower pad 534a of the porous pad 534 in the above embodiments, and description thereof is eliminated. The porous contact member 702 may comprise a member whose thickness is gradually thicker from the center toward the outer side of the member, or may comprise a member in which diameters of fine through-holes of the member 702 are gradually smaller from the center to the outer side of the member. These can be made by making a particle diameter of powder material gradually smaller from the center toward the outer side of the porous contact member, for example. Further, the inner diameters of the fine through-holes of the porous contact member 702 may be smaller gradually from the anode 704 side to the substrate W side. These can be made by making a particle

diameter of powder material gradually smaller from the center toward the surface which contacts the substrate. Further, the porous contact member 702 may be formed by superimposing a relatively hard porous member and a relatively soft porous member, or may comprise a member having a convex shape whose center projects downwardly.

On the other hand, the plating solution impregnated material 703 serves to hold a plating solution Q and to feed the plating solution Q between the surface of the porous contact member 702 and the seed layer 6 of the substrate W, and has substantially the same structure as the plating solution impregnated material 532 in the above embodiments, and hence explanation of the plating solution impregnated material 703 is eliminated.

Further, the anode 704 may comprise a metal to be plated, or an insoluble metal such as platinum or titanium, or an insoluble electrode comprising a metal on which platinum or the like is plated.

The anode 704 is preferably immersed in the plating solution Q up to the upper portion of the anode 704, and a space is preferably provided at the location above the upper part of the anode 704. This space stores gas such as oxygen gas generated in using the insoluble electrode, and a pressure in the electrode head 701 in its entirety can be increased by introducing air or the like into the space from the outside through a valve (not shown), or the amount of the plating solution flowing through the fine through-holes of the porous contact member 702 can be controlled due to weight of the plating solution.

The electrode head 701 is attached to the main shaft 710

by the supporting member 711 having a certain elasticity. Further, an air bag 709 is provided between the electrode head 701 and the main shaft 710. By increasing or decreasing air in the air bag 709, the electrode head 701 in its entirety is vertically movable to increase or decrease a pressure applied to the seed layer 6 of the substrate W.

The seal ring 708 provided at the bottom circumference of the housing 707 is formed by a material having an elasticity and a sealing property such as rubber or plastics, and the seal ring 708 serves to prevent the plating solution from leaking from the side surface of the porous contact member 702 at the time of plating. Further, even if the porous contact member 702 is brought out of contact with the seed layer 6 of the substrate W, the seal ring 708 may have a structure such that the seal ring 708 is not separated from the seed layer 6 of the substrate W to prevent the plating solution from leaking out. Further, the cathode electrodes 712 which are brought into contact with the seed layer 6 of the substrate W to supply power to the seed layer 6 are provided outside the seal ring 708.

In FIG. 33, the gap is provided between the porous contact member 702 and the plating solution impregnated material 703, and the plating solution Q exists in the gap. However, a soft sponge or the like may be provided in this gap. Further, the porous contact member 702 may contact the plating solution impregnated material 703 directly without providing a gap. In the latter case, if it is necessary to equalize an electric field according to the shape of the plating solution impregnated material 703, the shape of the porous contact member 702 may be

formed so as to conform to the shape of the plating solution impregnated material 703. Further, the electrode head 701 is attached to the main shaft 710 by the supporting member 711, and the air bag 709 is provided between the electrode head 701 and the main shaft 710. However, the electrode head 701 may be directly attached to the main shaft 710, and the main shaft 710 in its entirety may be moved by an actuator or the like.

FIG. 34 shows an overall structure of a plating apparatus. This plating apparatus has an integration control unit 721, an applied voltage control unit 722, a plating power source 723, a motion control unit 724, a pressurizing pump 725, an actuator 726, and a substrate stage 730.

This plating apparatus is a so-called face-up type electroplating apparatus, and the substrate W is placed on the substrate stage 730 in such a manner that the front face of the substrate faces upwardly. When plating is performed, the electrode head 701 is lowered with respect to the substrate W whose front face faces upward, and the surface of the porous contact member 702 is brought into contact with the seed layer 6 of the substrate W. Then, the cathode electrodes 712 contact the seed layer 6 on the surface of the substrate W so that current can be supplied to the seed layer 6. In this embodiment, the substrate W is held in such a state that the front face of the substrate faces upwardly (face-up). However, the substrate W may be held in such a manner that a front face of the substrate W faces downwardly (face-down), or the substrate may be held up and down.

On the other hand, the pores provided in the anode 704, the interior of the plating solution impregnated material 703,

and the interior of the porous contact member 702 are filled with the plating solution Q in the electrode head 701, and hence the plating solution Q is supplied to the upper surface (front surface) of the seed layer 6 of the substrate W. The timing for supplying the plating solution may be before or after contact occurring between the porous contact member 702 and the seed layer 6. However, it is desirable to supply the plating solution immediately before the contact between the porous contact member 702 and the seed layer 6 in consideration of the escape of air.

In this state, a plating voltage is applied between the anode 704 and the seed layer 6 of the substrate W to flow current, and plating (for example, copper plating) is performed on the surface of the seed layer 6. Then, the plating solution impregnated material 703 and the porous contact member 702 are positioned between the anode 704 and the seed layer 6 of the substrate W, and the porous contact member 702 contacts the raised portions of the substrate W. Therefore, a metal is deposited preferentially into the fine recesses of the substrate W to which the plating solution is liable to be supplied, thus filling the metal into trenches or the like preferentially.

Further, in a case where additives containing components for suppressing deposition of a plated film and attached to the raised portions where a current density becomes high are used in the plating solution, the additives act on portions as the raised portions other than the fine recesses of the substrate, and deposition of a plated film is further enhanced preferentially in the fine recesses.

When plating is performed to some degree, the application

state of the plating voltage is varied by the applied voltage control unit 722 on the basis of information from the integration control unit 721. Further, the actuator 726 and the pressurizing pump 725 are operated by the motion control unit 724 so that a state for pressing the electrode head 701 against the substrate W is varied in connection with a change of the application state of the plating voltage.

For example, when components in the plating solution are decreased, the application of the plating voltage is stopped by the applied voltage control unit 722, and at the same time, the location of the seed layer 6 on the substrate W and the porous contact member 702 of the electrode head 701 is moved by the motion control unit 724. Thus, the plating solution is newly supplied, and plating is performed on the portions where plating condition is insufficient, thus obtaining a homogeneous plated film.

As described above, after plating is performed for a certain period of time while a change of state of applied voltage and a change of state for pressing the porous contact member 702 against the seed layer 6 are correlated by the integration control unit 721, the applied voltage control unit 722 and the motion control unit 724, the electrode head 701 is raised to separate the porous contact member 702 from the plated surface of the substrate W.

At this time, in some cases, metal deposit remains in the voids of the porous contact member 702. However, the metal deposit can be easily removed by immersing the surface of the porous contact member 702 in an etching tank (not shown) which is separately provided.

According to the present invention, since plating can be

performed preferentially in fine recesses such as trenches, the consumption of the plating solution can be reduced. Further, since a plating tank having a volume enclosed by the substrate and the porous contact member can be constructed, the amount of the plating solution used can be greatly reduced. Further, for example, replenishment of the plating solution into fine recesses is promoted by moving motion or pressing motion while plating is stopped, and hence generation of voids can be effectively suppressed.

As described above, according to the present invention, in the damascene process in which embedding plating is performed on the substrate using a metal such as copper, the present invention can be advantageously utilized.

Next, the present invention will be described in further detail by the following examples. However, the present invention is not restricted at all by these examples.

Example

A barrier metal process was performed on the substrate W having narrow trenches (having a depth of 1 μm and a width of 0.18 μm) 4a and wide trenches (having a width of 100 μm) 4b having a larger width than the narrow trenches by a conventional method. Next, the seed layer 6 having a thickness of 80 nm was formed on the substrate W by sputtering, and then the substrate W was used as a testing sample.

This testing sample was plated using an acid copper plating solution having composition shown in Table 1 by a plating apparatus having the electrode head (the anode 704 is composed of copper containing phosphorus having holes) 701 having the structure shown

in FIG. 34. The plating condition is shown in FIG. 36. As a current-flowing pattern, first, in a state such that the porous contact member 702 was brought out of contact with the seed layer 6, plating was started at a plating voltage of 1V, and after an elapse of ten seconds, current supply was stopped. Thereafter, the porous contact member 702 was brought into contact with the seed layer 6, running-in (fine up-and-down motion) was performed for one second, and a plating voltage was applied for five seconds. Next, application of plating voltage was stopped, and at the same time, the porous contact member 702 was brought out of contact with the seed layer 6. Then, the rotary motion of the substrate W was performed in this non-contact state, and then the porous contact member 702 was brought into contact with the seed layer 6, and a plating voltage was applied for five seconds. The application of plating voltage, the state of contact between the seed layer 6 and the porous contact member 702, and the state of non-contact between the seed layer 6 and the porous contact member 702 were kept for eight minutes, and then plating was finished. Further, during this time, the pressure P_6 in the anode chamber 706, and the pressure P_7 in the air bag 709 were adjusted as shown in FIG. 36.

By the above plating, the copper layer 7 shown schematically in FIG. 37 was obtained.

(composition of acid copper plating bath)

$Cu_2SO_4 \cdot 5H_2O$	225 g/L
H_2SO_4	55 g/L
Cl_2	60 ppm
polyethylene glycol (MW Ca. 10000)	550 mg/L

bis (3-sulfopropyl) disulfide (SPS)	20 mg/L
Janus green	1 mg/L

As is apparent from FIG. 37, according to the present invention, precipitation of a plated film takes place preferentially in the fine recesses such as narrow trenches 4a and wide trenches 4b, and precipitation of a plated film on the raised portions is suppressed. As a result, copper can be embedded perfectly into the fine recesses such as narrow trenches 4a and wide trenches 4b in such a state that the thickness of the copper layer 7 is not thick.

This mechanism can be shown in FIG. 38. Specifically, at the initial stage, the metal surface in the recesses has a height of a_1, whereas the metal surface at the raised portions has a height of a_2 from the bottom of the recesses. Then, according to the present invention, precipitation of a plated film takes place preferentially in the recesses and precipitation of a plated film is suppressed at the raised portions. As a result, a plating rate in the recesses becomes h and a plating rate at the raised portions becomes H. As a result of this rate difference, when the raised portions and the recesses have the same height (h_1), both plating rates have no difference, and hence plating is performed in the same rate.

FIG. 39 shows a plating apparatus according to still another embodiment of the present invention. The plating apparatus according to this embodiment shown in FIG. 39 is different from the plating apparatus shown in FIG. 29 in the following respects.

Specifically, the electrode head 502 has a pressing mechanism comprising an air bag 548 in this embodiment for pressing

the lower pad 534a against the surface (surface to be plated) of the substrate W held by the substrate stage 504. More specifically, in this embodiment, a ring-shaped air bag (pressing mechanism) 548 is provided between the lower surface of the top wall of the rotatable housing 520 and the upper surface of the top wall of the vertically movable housing 522, and this air bag 548 is connected to a pressurized fluid source (not shown) through a fluid introduction pipe 549.

Thus, the swing arm 500 is fixed at a predetermined position (process position) so as not to move up and down, and then the interior of the air bag 548 is pressurized under a pressure of P_8, whereby the lower pad 534a is uniformly pressed against the surface (surface to be plated) of the substrate W held by the substrate stage 504 under a desired pressure. Thereafter, the pressure P_8 is restored to an atmospheric pressure, whereby pressing of the lower pad 534a against the substrate W is released.

The cathode electrodes 512 are electrically connected to the cathode of the plating power source 560, and the anode 526 is electrically connected to the anode of the plating power source 560.

Next, an operation for conducting plating by this plating apparatus will be described below. First, in a state that the substrate W is attracted to and held by the upper surface of the substrate stage 504, the substrate stage 504 is raised to bring the peripheral portion of the substrate W into contact with the cathode electrodes 512, thus making it possible to supply current to the substrate W. Then, the substrate stage 504 is further raised to press the seal member 514 against the upper surface

of the peripheral portion of the substrate W, thereby hermetically sealing the peripheral portion of the substrate W by the seal member 514.

On the other hand, the electrode head 502 is moved from a position (idling position) where replacement of the plating solution, removal of bubbles, and the like are conducted by idling to a predetermined position (process position) in such a state that the plating solution Q is held inside the electrode head 502. Specifically, the swing arm 500 is once raised and further swung, whereby the electrode head 502 is located immediately above the substrate stage 504. Thereafter, the electrode head 502 is lowered, and when the electrode head 502 reaches the predetermined position (process position), the electrode head 502 is stopped. Then, the anode chamber 530 is pressurized, and the plating solution Q held by the electrode head 502 is discharged from the lower surface of the porous pad 534. Next, pressurized air is introduced into the air bag 548, and the lower pad 534a is pressed downwardly.

In this state, the electrode head 502 and the substrate stage 504 are rotated (rotated on their own axes), respectively. Therefore, even if the plating solution Q exists in the gaps S generated locally between the porous member 528 (lower pad 534a) and the surface of the substrate W, caused by surface roughness of the surface of the porous member 528 (lower pad 534a) and undulations or warpage produced in the porous member 528 (lower pad 534a) when the porous member 528 (lower pad 534a) is pressed against the surface of the substrate W as shown in FIG. 40, the plating solution Q existing in the gaps S is removed outwardly

by a centrifugal force generated by this rotation.

In this manner, by removing the plating solution Q, the entire surface of the porous member 528 (lower pad 534a) can be uniformly pressed against the surface S of the substrate W and be brought into close contact with the surface S of the substrate W.

In this embodiment, after the lower pad 534a is pressed downwardly, the electrode head 502 and the substrate stage 504 are rotated, respectively. However, when the lower pad 534a is pressed downwardly by introducing the pressurized air into the air bag 548, the electrode head 502 and the substrate stage 504 may be rotated in advance, and this rotation may be continued for a certain period of time after this pressing.

After the electrode head 502 and the substrate stage 504 are rotated for a sufficient time to remove the plating solution Q existing in the gaps S generated locally between the porous member 528 (lower pad 534a) and the surface P of the substrate W, and to press the entire surface of the porous member 528 (lower pad 534a) uniformly against the surface P of the substrate W and bring the entire surface of the porous member 528 into close contact with the surface p of the substrate W, this rotation is stopped.

Next, the cathode electrodes 512 are connected to the cathode of the plating power source 560 and the anode 526 is connected to the anode of the plating power source 560, thereby plating the surface of the substrate W. In this manner, the lower pad 534a is pressed against the surface of the substrate W held by the substrate stage 504 under a desired pressure, and adhesiveness between the lower pad 534a and the substrate W is heightened,

thereby plating the surface of the substrate W. Therefore, the gaps between the lower pad 534a and portions other than fine recesses for interconnects such as trenches in the surface, to be plated, of the substrate W (portions other than pattern) are eliminated, and hence a plated film is selectively deposited in the fine recesses for interconnects formed in the surface of the substrate.

After plating is performed for a certain period of time, the cathode electrodes 512 and the anode 526 are disconnected from the plating power source 560, and the anode chamber 530 is restored to an atmospheric pressure, and further the air bag 548 is restored to an atmospheric pressure, whereby pressing of the lower pad 534a against the substrate W is released. Then, the electrode head 502 is raised.

The above operation is repeated a predetermined number of times, if necessary, and the copper layer 7 (see FIG. 1B) having a sufficient thickness enough to fill fine recesses for interconnects is formed on the surface (surface to be plated) of the substrate W, and then the electrode head 502 is rotated to be returned to its original position (idling position).

FIG. 41 shows essential parts of the plating apparatus according to still another embodiment of the present invention. The plating apparatus according to the embodiment shown in FIG. 41 is different from the plating apparatus shown in FIG. 39 in that a piezo transducer 590 is attached to the upper surface of the substrate placing section of the substrate stage 504, and vibrations in a vertical direction perpendicular to the surface of the substrate W placed on the substrate stage 504 are imparted

to the substrate W by the piezo transducer 590.

In this embodiment, the lower pad 534a is pressed against the substrate W held by the substrate stage 504 in the same manner as the above, and then the substrate W is vibrated by the piezo transducer 590 up and down for a certain period of time. Alternatively, when the lower pad 534a is pressed against the substrate W, the substrate W is vibrated up and down by the piezo transducer 590 in advance, and this vibration is continued for a certain period of time after the lower pad 534a is pressed against the substrate W. Therefore, even if the plating solution Q exists in the gaps S generated locally between the porous member 528 (lower pad 534a) and the surface P of the substrate W, the plating solution Q existing in the gaps S can be removed outwardly due to this vibration. Particularly, as in this embodiment, by vibrating the substrate W vertically to the surface, to be plated, of the substrate W, the porous member is adapted not to be brought in sliding contact with the surface of the substrate W, and thus the plated surface is prevented from being damaged. Further, as a vibrator, the piezo transducer 590 is used to make a mechanism compact.

FIG. 42 shows essential parts of a plating apparatus according to still another embodiment of the present invention. The plating apparatus according to the embodiment shown in FIG. 42 is different from the plating apparatus shown in FIG. 39 in that a storage tank 504g for holding a liquid such as pure water is formed on the upper surface of the substrate stage 504, and an ultrasonic oscillator 592 for imparting an ultrasonic wave to the liquid in the storage tank 504g to vibrate the liquid at

a high frequency is provided in the storage tank 504g.

In this embodiment, the storage tank 504g of the substrate stage 504 is filled with a liquid such as pure water, and the substrate W is attracted to and held by the upper surface of the substrate stage 504 in the same manner as the above. At this time, the substrate W held by the substrate stage 504 is brought into contact with the liquid in the storage tank 504g of the substrate stage 504. After the lower pad 534a is pressed against the substrate W held by the substrate stage 504, ultrasonic vibration is imparted to the liquid in the storage tank 504g of the substrate stage 504 by the ultrasonic oscillator 592. Then, the ultrasonic vibration of the liquid is transmitted to the substrate W to vibrate the substrate W, and is further transmitted from the plating solution Q to the porous member 528 to vibrate the plating solution Q and the porous member 528. Thus, in the same manner as the above, the plating solution Q existing in the gaps S generated locally between the porous member 528 (lower pad 534a) and the surface P of the substrate W can be removed outwardly due to this vibration.

When the lower pad 534a is pressed against the substrate W, ultrasonic vibration may be imparted to the liquid in the storage tank 504g of the substrate stage 504 by the ultrasonic oscillator 592 in advance.

FIG. 43 shows essential parts of a plating apparatus according to still another embodiment of the present invention. The plating apparatus according to the embodiment shown in FIG. 43 is different from the plating apparatus shown in FIG. 39 in that a pressure port 594 is attached to the top wall of the

vertically movable housing 522 which defines the anode chamber 530 therein, and a vacuum pump 598 serving as a pressure control unit is connected to the pressure port 594 through an opening and closing valve 596.

In this embodiment, the anode chamber 530 is evacuated by operating the vacuum pump 598 to develop a pressure in the anode chamber 530 lower than an atmospheric pressure (negative pressure). As shown in FIG. 44, the plating solution Q existing in the gaps S between the porous member 528 (the lower pad 534a) and the surface P, to be plated, of the substrate W is drawn to accelerate a flow of the plating solution Q into the anode chamber 530 through the interior of the porous member 528 (lower pad 534a), thereby removing the plating solution Q from the gaps S. This drawing and removing operation of the plating solution is performed in advance after the lower pad 534a is pressed against the substrate W held by the substrate stage 504 or when the lower pad 534a is pressed against the substrate W. However, such drawing and removing operation of the plating solution may continue to be performed also during plating.

Further, in the embodiment shown in FIG. 43, the vacuum pump 598 is connected to the pressure port 594 through the opening and closing valve 596. However, a pressurizing pump may be connected instead of the vacuum pump 598, and an exhaust port may be further provided in the vertically movable housing, whereby the plating solution Q in the anode chamber 530 and further the porous member 528 may be vibrated using pressure vibration caused by repetition of pressurizing of the anode chamber 530 by the pressurizing pump and depressurizing of the anode chamber 530

by evacuation from the exhaust port.

As described above in detail, according to the present invention, when the porous member is pressed against the surface of the substrate held by the substrate stage under a desired pressure, the plating solution existing in the gaps generated locally between the porous member and the surface of the substrate W is removed, and hence plating can be performed in such a state that the entire surface of the porous member is uniformly brought into close contact with the surface of the substrate W without increasing loads. Thus, plating is performed preferentially into trenches or via holes to embed an interconnect material (metal film) therein, and hence flatness of the surface after plating can be improved. Accordingly, a load of a selective etching process applied to the raised portions such as by CMP can be reduced or eliminated, and hence, in addition to a reduction in costs, problems unique to CMP such as dishing or oxide erosion can be solved.

FIGS. 46 through 49 show essential parts of a plating apparatus according to still another embodiment of the present invention. The difference between this plating apparatus and the plating apparatus shown in FIG. 29 is as follows:

Specifically, as shown in FIG. 46, the plating apparatus has a plating section 630 for performing a plating process and its associated processes, and an idling stage 632 is disposed adjacent to the plating section 630. Further, an electrode arm portion 636 having the electrode head 502 which is supported by the forward end of the swing arm 500 swung about a rotation shaft 634 and is movable between the plating section 630 and the idling

stage 632 is provided. Further, a pre-coating and recovery arm 638, and fixed nozzles 640 for ejecting pure water, a chemical liquid such as ionized water, and gas or the like to the substrate are disposed at the side of the plating section 630. In this embodiment, three fixed nozzles 640 are provided, and one of the fixed nozzles 640 is used for supplying pure water.

Further, as shown in FIG. 46, the porous member 528 disposed in the anode chamber 530 has a multi-layered structure in which porous materials are laminated in three layers and a space is provided between the adjacent layers. Specifically, the porous member 528 comprises a plating solution impregnated material 532, and a porous pad 534 composed of a lower pad 534a and an upper pad 534b, and a first space 642a is provided between the lower pad 534a and the upper pad 534b, and a second space 642b is provided between the upper pad 534b and the plating solution impregnated material 532.

The first space 642a is provided between the lower pad 534a and the upper pad 534b, a new plating solution is supplied into the first space 642a, and further into the lower pad 534a located below the first space 642a, and is held in advance. Then, this new plating solution is supplied to the substrate W through the lower pad 534a immediately before plating. Therefore, plating can be performed using the new plating solution at all times by supplying a smaller amount of plating solution. That is, in this embodiment, as described below, a pressurized fluid is introduced into the anode chamber 530 (upper part of the anode 530) to pressurize the anode chamber 530 under a pressure of P_{10}, whereby the plating solution in the anode chamber 530 is supplied to the

substrate. At this time, the new plating solution is held in advance in the first space 642a mainly, and further in the lower pad 534a located below the first space 642a. Therefore, the plating solution in the anode chamber 530 which allows the anode 526 to be immersed can be prevented from being mixed with the new plating solution to be supplied to the substrate.

Further, the second space 642b is provided between the upper pad 534b and the plating solution impregnated material 532, and the second space 642b can be utilized as a space for holding a new plating solution mainly. Further, a new plating solution in the second space 642b is prevented from being mixed with the plating solution in the anode chamber 530 which allows the anode 526 to be immersed.

In order to replace the used plating solution in the first space 642a with a new plating solution by introducing the new plating solution into the first space 642a, the vertically movable housing 522 has a plating solution supply unit 652 for discharging and supplying a plating solution into the first space 642a, and a plating solution discharge unit 654 for drawing in and discharging the plating solution in the first space 642a at diametrically opposite locations of the vertically movable housing 522. As shown in FIG. 47, the plating solution supply unit 652 is configured such that a plurality of discharge ports 656 provided at the locations facing the first space 642a of the vertically movable housing 522, and a connecting port 658 communicating with the discharge ports 656 and passing through the vertically movable housing 522 are provided, and a plating solution supply port 660 communicating with the connecting port

658 is attached to the plating solution supply unit 652. Further, the plating solution discharge unit 654 is configured such that a plurality of suction ports 662 provided at the locations facing the first space 642a of the vertically movable housing 522, and a connecting port 664 communicating with the suction ports 662 and passing through the vertically movable housing 522 are provided, and a plating solution discharge port 666 communicating with the connecting port 664 is attached to the plating solution discharge unit 654.

Thus, while a new plating solution is supplied from the plating solution supply unit 652 into the first space 642a, the plating solution is withdrawn from the first space 642a through the plating solution discharge unit 654, whereby the used plating solution in the first space 642a can be replaced with the new plating solution.

The electrode head 502 has a pressing and separating mechanism having an air bag 570 for pressing the lower pad 534a against the surface (surface to be plated) of the substrate W held by the substrate stage 504. Specifically, in this embodiment, a ring-shaped air bag (pressing mechanism) 570 is provided between the lower surface of the top wall of the rotatable housing 520 and the upper surface of the top wall of the vertically movable housing 522, and this air bag 570 is connected to a pressurized fluid source (not shown) through a fluid introduction pipe 572. Thus, the swing arm 500 is fixed at a predetermined position (process position) so as not to move up and down, and then the interior of the air bag 570 is pressurized under a pressure of P_9, whereby the lower pad 534a is uniformly pressed against the

surface (surface to be plated) of the substrate W held by the substrate stage 504 under a desired pressure. Thereafter, the pressure P_9 is restored to an atmospheric pressure, whereby pressing of the lower pad 534a against the substrate W is released.

A plating solution suction pipe 574 for drawing in a plating solution within the anode chamber 530, and a pressurized fluid introduction pipe 576 for introducing a pressurized fluid are attached to the vertically movable housing 522. A number of pores 526a are provided within the anode 526. Therefore, a plating solution in the anode chamber 530 is drawn in through the plating solution suction pipe 574 in such a state that the porous member 528 is immersed in the plating solution to seal the anode chamber 530 hermetically. Thus, the plating solution is supplied to the upper surface of the substrate W by sucking the plating solution from the porous member 528 into the anode chamber 530 and pressurizing the interior of the anode chamber 530 under a pressure of P_{10}.

FIG. 48 shows the state in which the electrode head 502 is moved immediately above the idling stage 632, and then lowered to supply a new plating solution to the anode chamber 530 of the electrode head 502. The idling stage 632 has a plating solution tray 600 for storing a new plating solution therein, for example. Then, the porous member 528 is immersed in the plating solution stored in the plating solution tray 600 to seal the anode chamber 530 hermetically. In this state, the plating solution in the anode chamber 530 is sucked through the plating solution suction pipe 574, and a new plating solution in the plating solution tray 600 is sucked from the porous member 528 into the anode chamber

530. In this manner, when the sucked new plating solution reaches the location above the first space 642a, more preferably the location above the second space 642b, sucking of the plating solution is stopped. In this manner, the new plating solution is primarily held in the first space 642a, in the lower pad 534a located below the first space 642a, more preferably in the second space 642b, and in the upper pad 534b located below the second space 642b. Sucking of the plating solution at this time is preferably performed at a slow speed within the speed range so as not lower the throughput.

FIG. 49 shows the state in which a new plating solution is supplied to the anode chamber 530 of the electrode head 502. In this embodiment, for example, the plating solution tray 600 is filled with a new plating solution, or a plating solution is circulated through the plating solution tray 600. Then, the porous member 528 is immersed in the plating solution in the plating solution tray 600 to seal the anode chamber 530 hermetically. In this state, the new plating solution is supplied into the first space 642a by opening the plating solution supply port 660, and at the same time, the plating solution is withdrawn from the first space 642a by opening the plating solution supply port 660, and hence the used plating solution in the first space 642a is replaced mainly with a new plating solution. After this replacement, supply of the plating solution from the plating solution supply port 660 is stopped, and at the same time, the plating solution supply port 660 is closed, or after the plating solution discharge port 666 is closed, supply of the plating solution from the plating solution supply port 660 is continued for a short period of time,

and then this supply of the plating solution is stopped. Replacement of the plating solution at this time is preferably performed at a slow speed within the speed range so as not to lower the throughput. Further, by storing a new plating solution in the plating solution tray 600, a part of used plating solution in the lower pad 534a located below the first space 624a can be replaced with a new plating solution.

According to this embodiment, by the above two methods, a new plating solution can be primarily held in the first space 642a, preferably in the lower pad 534a located below the first space 642a, more preferably in the second space 642b, and in the upper pad 534b located below the second space 642b.

Next, operation for performing plating in this plating apparatus will be described below.

First, in a state that the substrate W is attracted to and held by the upper surface of the substrate stage 504, the substrate stage 504 is raised to bring the peripheral portion of the substrate W into contact with the cathode electrodes 512, thus making it possible to supply current to the substrate W. Then, the substrate stage 504 is further raised to press the seal member 512 against the upper surface of the peripheral portion of the substrate W, thereby hermetically sealing the peripheral portion of the substrate W by the seal member. On the other hand, for the electrode head 502, in the idling stage 632, as described above, a new plating solution is primarily held in the first space 642a, preferably in the lower pad 534a located below the first space 642a, more preferably in the second space 642b, and in the upper pad 534b located below the second space 642b. Then, the electrode

head 502 is located at a predetermined position. Specifically, the swing arm 500 is once raised and further swung, whereby the electrode head 502 is located immediately above the substrate stage 504. Thereafter, the electrode head 502 is lowered, and when the electrode head 502 reaches the predetermined position (process position), the electrode head 502 is stopped. Then, the anode chamber 530 is pressurized to a pressure of P_{10}, and the plating solution Q held by the electrode head 502 is discharged from the lower surface of the porous pad 534.

Thus, the plating solution held in the first space 642a or the like, and the lower pad 534a located below the first space 642a, can be prevented from being mixed with the plating solution held in the anode chamber 530 which allows the anode 526 to be immersed, and can be supplied to the substrate W.

Next, the lower pad 534a is pressed downwardly by introducing a pressurized air into the air bag 570 to press the lower pad 534a against the surface (surface to be plated) of the substrate W under a desired pressure. In this state, the electrode head 502 and the substrate stage 504 are rotated (rotated on their own axes). In this manner, before plating, the lower pad 534a is pressed against the surface of the substrate W held by the substrate stage 504 under a desired pressure, and the lower pad 534a and the substrate W are moved relatively to each other to heighten adhesiveness between the lower pad 534a and the substrate W.

After rotation of the electrode head 502 and the substrate stage 504 is stopped, the cathode electrodes 512 are connected to the cathode of the plating power source 560 and the anode 526

is connected to the anode of the plating power source 560, thereby plating the surface of the substrate W. After plating continues to be performed for a certain period of time, the cathode electrodes 512 and the anode 526 are disconnected from the plating power source 560, and the anode chamber 530 is restored to an atmospheric pressure and the air bag 570 is restored to an atmospheric pressure. Thereafter, the swing arm 500 is raised and further swung to return the electrode head 502 to its original position (idling position). The above operation is repeated a predetermined number of times, if necessary, and the copper layer 7 (see FIG. 1B) having a sufficient thickness to fill fine recesses for interconnects is formed on the surface (surface to be plated) of the substrate W, and then plating is finished.

According to the present invention, a new plating solution is held in advance in the porous member having a multi-layered structure, and the new plating solution is supplied to the substrate through the porous member immediately before plating. Therefore, the plating solution in which the anode is immersed is prevented from being mixed with the new plating solution to be supplied to the substrate, and plating can be performed using the new plating solution at all times by supplying a smaller amount of plating solution. Thus, the consumption of the plating solution can be reduced. Further, the present invention can easily cope with a process which uses various plating solutions.